The Economic and Environmental Implications of Incorporating Composting Barns into New Zealand Dairy Systems

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The New Zealand dairy industry is challenged with the task of improving their environmental performance while at the same time maintaining or increasing farm productivity and profitability. Composting barns have been suggested as one potential solution to improve a farm's environmental and financial performance largely through improved productivity and duration-controlled grazing. This research project used farm systems modelling utilising Overseer® and Excel to identify the economic and environmental implications of incorporating a composting barn system on a Canterbury dairy farm. Preliminary work from this study suggested that composting barns could improve both the economic and environmental performance of a dairy farm, however a large number of assumptions had to be made to obtain these results. Thus, the key findings from this study was not the overall outcome, but rather the identification of the critical components of the system that affected nitrogen (N) leaching, greenhouse gas emissions and farm profitability. The incorporation of composting barns on the dairy farm altered the N leaching profile from one dominated by urinary N leaching to one dominated by N loss from fertiliser and soil organic matter mineralisation. The inability of Overseer® to model effluent and composting processes in the composting barn impacted on the nitrous oxide (N_2O) results and were deemed not representative of the system. A small decrease in methane (CH_4) emissions were observed with the incorporation of the composting barn on farm and was an indirect result of an improvement in feed conversion efficiency from incorporating supplementary feeding within the composting barn system. Economic profitability appeared to increase with the incorporation of composting barns on farm. The internal rate of return (IRR) before interest and tax increased from 8.45% without the barn to 11.62% with the barn. The marginal return was valued at 27.6%. Milk payout was identified as the key component affecting the economic performance of the composting barn system with every one dollar reduction in the payout reducing the IRR by 2.4%.

Keywords: dairy, farm systems, composting barns, housing, duration-controlled grazing, nitrogen leaching, greenhouse gases, Overseer®, profitability

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Table of Contents

List of Tables

List of Figures

Chapter 1

Introduction

New Zealand agriculture faces increasing pressure to improve its environmental sustainability. Nutrient losses from dairy farms, and in particular nitrate leaching losses, have been identified by the Government as a key area of concern requiring mitigation strategies. Under the New Zealand government's National Policy Statement for Freshwater Management 2014 (MfE, 2017) many regional councils have set nutrient discharge limits which must be met by farmers in order to obtain resource consent. Thus, current management practices including year-round pasture grazing may need to be revised in order to meet future obligations.

One potential solution for the New Zealand dairy industry may be the adoption of composting barns into the farming system. Composting barns are an alternative loose housing facility that were first developed in Minnesota in 2001 to improve cow comfort and longevity. The barns provide a large, open resting area typically comprised of sawdust. Dairy manure is excreted directly onto the bedding and is composted *in situ* with the aid of daily tilling and ventilation. Provided the key design and management principles are understood and followed, the composting barn will provide a dry and comfortable surface for cows to ruminate and rest on.

While composting systems are working well in North America, there is limited data regarding their suitability to New Zealand farming conditions. However, a small number of farmers who have adopted the system in New Zealand are showing early success particularly in terms of improved economic and animal welfare performance. While the environmental implications have not been closely studied, the ability to have cows off the milking platform and housed for up to 20 hours a day during 'at-risk' periods in late autumn and winter indicates potential improvements for nitrate leaching and nitrous oxide emissions.

Literature pertaining to composting barns is largely based on overseas research regarding compost management and animal welfare. Limited research is available regarding the economics of composting barns and, in most cases, is related to cost savings in animal health (i.e. lameness and mastitis). To date, there is no literature investigating the ability to incorporate composting barns within a pastoral system, and certainly not within a New Zealand context. Similarly, data pertaining to the environmental sustainability of composting barns is severely lacking and if these barns are to be adopted in New Zealand then urgent research in this area is required.

As such, this dissertation aims to help fill existing gaps in the literature by focusing on the environmental, including nitrate leaching and greenhouse gas emissions, and economic implications of incorporating composting barns onto New Zealand dairy farms. As composting barns are a very new concept in New Zealand dairying, thus requiring a large number of assumptions to be made, the aim of this dissertation is not to determine the economic and environmental viability of the barn, but rather to identify the critical components that will affect the environmental and economic success of composting barn systems. Both qualitative and quantitative data will be used to create a mixed methods research approach that will allow environmental and economic comparisons to be made on a base farm (Lincoln University Dairy Farm; LUDF) with and without a composting barn.

This study will begin with a review of the existing literature in Chapter 2 including a general description of dairy housing facilities, the potential ability to incorporate composting barns into New Zealand dairying, and an overview of the animal welfare and environmental implications. Chapter 3 outlines the methodology used to model the environmental and economic implications while Chapter 4 provides an outline of the existing LUDF system with and without a composting barn. Chapters 5 and 6 comprise the economic and environmental results, respectively, and the key assumptions used to compile these. Chapter 7 provides a discussion of these results including scenario analyses. Finally, the conclusions can be found in Chapter 8 with limitations and future research in Chapter 9.

Chapter 2

Literature Review

2.1 Introduction

The purpose of this literature review is to investigate the research surrounding composting barns with a particular focus on animal welfare and environmental sustainability. In addition, the ability for composting barns to fit within the context of New Zealand dairy systems was also explored. There is a great deal of research available, mainly from the United States, regarding the management of composting barns and their impact on animal welfare in comparison to other housing facilities of which this review aims to analyse and condense. However, information regarding the environmental sustainability of composting barns is very limited and in addition no studies, to the writer's knowledge, have compared the barns to pastoral systems. As such, urgent research is required in this area to be able to understand the potential for composting barns in the New Zealand environment. It is hoped that this research project will stimulate such investigations.

This review is based on peer-reviewed research papers and in some instances non peer-reviewed government and industry reports as well as farmer conference proceedings in cases where information was deemed to be lacking. It should be noted that this review refers to composting barns rather than 'compost barns' or 'compost bedded pack barns' as is seen in literature to avoid confusion between a similar system where dairy excreta is collected, dried and used as bedding.

2.2 Housing Facilities

2.2.1 Freestall Barns

Currently, there are two main types of housing facilities used in New Zealand – freestall and loose housed barns. Freestall barns are a fully covered facility usually built with steel roofing. The barn is designed to house cows for prolonged periods of time, particularly over the winter months. It has a solid concrete floor allowing free movement and has separate bedding and feeding areas. The bedding area is typically covered with a soft material, such as rubber mats or water mattresses, and is separated to provide individual cubicles (stalls) where cows can ruminate and rest. These stalls are designed to allow effluent to be deposited onto the concrete alleyways which are regularly scraped to remove manure and deposit it into an effluent pond. Feeding areas are kept separate from the bedding area in a central lane, providing free access for cows to enter and exit (IPENZ, 2015).

2.2.2 Loose Housed Barns

In comparison, loose housed barns are used to house cows for extended periods during adverse weather, including hot/humid periods in summer. These systems vary with either slatted concrete flooring or soft bedding material. Slatted concrete systems are fully covered, usually with a plastic film over a framed roof. The slatted floor allows effluent to drain through and be captured below in a bunker for an extended time before it must be emptied. Some loose housed, slatted barns have a soft material covering the concrete such as rubber mats or straw. Design of the barn includes a strip of solid concrete along the outside edge to provide a feeding area (IPENZ, 2015).

Alternative to slatted concrete is a soft bedding material loose housed barn. These barns are also fully covered with either a plastic or steel roof. Rather than concrete, the base layer is a soft material which will absorb a small amount of effluent such as woodchip, sawdust or straw. The material must be regularly topped up and maintained to ensure it remains dry, hygienic and comfortable. These barns tend to have no side walls to aid with drying and ventilation. Like slatted barns, a solid concrete strip surrounds the long edges of the barn to provide a feeding area (IPENZ, 2015).

2.2.3 Composting Barns

In addition to the previous housing facilities are composting barns which are a new concept in New Zealand dairy housing. Overseas however, they have been successfully implemented in North American, European and Israeli dairy systems after the first barn was built in southern Minnesota in 2001 (Barberg *et al*., 2007). The main purpose behind the transition from freestall to composting barns in America was to improve cow comfort and longevity. Composting barns are similar to loose housed barns in that they are fully covered with a steel roof and have a soft bedding material typically comprised of woodchip and sawdust that is topped up throughout the season. The key characteristic of the barn that separates it from other loose housing systems is that the cows excrete directly onto the bedding creating *in situ* composting. Adequate ventilation, through the design of the barn, and daily tilling is essential to ensure the bedding remains dry, warm and sweet-smelling (Barberg *et al*., 2007; Janni *et al*., 2007). In a well-managed system, the compost remains inside the barn for 12 months before it must be taken out, used as fertiliser, and replaced. Like other housing facilities, composting barns in New Zealand require a shift from traditional year-round pasture grazing to a system where cows spend part of everyday, up to 20 hours, inside the barn (Woodford, 2017).

The major benefits associated with these barns compared to other housing facilities include improved cow cleanliness, improved feet and leg health, ease of manure handling, increased production, increased longevity, low investment costs, less concern with cow size and in some cases decreased somatic cell count (Barberg *et al*., 2007; Eckelcamp, 2014; Janni *et al*., 2007; Lobeck *et al*., 2011; Ofner-Schrock *et al*., 2015). On the other hand, the key constraints to the adoption of composting barns are the cost and availability of bedding (Barberg *et al*., 2007, Lobeck *et al*., 2011), and management of the bedded pack (Lobeck *et al*., 2011).

Design

The structure of the composting barn may vary depending on the individual farmer but typically consists of an open resting area usually covered in a woodchip/sawdust bedding, a concrete feed alley and in some cases a 1.2 metre wall surrounding the bedded pack with walkways every 35 – 40 m to allow cow and equipment access (Fig. 2.1; Barberg *et al*., 2007; Eckelcamp, 2014; Janni *et al*., 2007). Alternatively, instead of a high wall, the resting area may be sunken in to retain the bedding within the resting space, however this may allow additional moisture to get into the pack if the outside areas are not well designed. Feed bunk space is suggested to be set at 46.0 – 76.2 cm/cow with a minimum of two water troughs that are separated from the resting area to decrease the risk of moisture entering the pack (Bewley *et al*., 2012).

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Figure 2.1 Composting barn layout with two walkways, drive-by feeding. Water troughs are against the concrete wall separating the compost resting area from the feed alley. Adapted from Barberg et al. (2007).

Ventilation is also key to encourage air filtration and remove excess heat and moisture that is generated from the composting process. Natural ventilation can be maximised by positioning the barn to take advantage of the prevailing wind and constructing high sidewalls (4.26 – 4.90 m; Bewley *et al*., 2012). Having the correct roof pitch is important as barns with too flat of a roof will limit ventilation and create pockets of warm, moist air within the barn. A pitch of at least 18.43° (4:12) is recommended with ridge vent openings of at least 6.72 cm for every 3.05 m of roof width with a minimum opening of 30.48 cm (Bewley *et al*., 2012). Janni *et al*. (2007) also recommends elevating the barn slightly above the ground to minimise runoff from rain entering the bedding. In addition, to prevent excess moisture from entering the pack roof overhangs should be a minimum of one metre or preferably the length of one-third of the height of the sidewall opening (Bewley *et al*., 2012).

Bedding

Initially 450 – 500 mm of a woodchip and sawdust mix, preferably from pine or other soft woods, is put down to start the compost bedded pack (Bewley *et al*., 2012; Janni *et al*., 2007). It is suggested that the fine particles in these products improve handling, mixing, aeration and biological activity (Janni *et al*., 2007), while the high lignin content provides some level of resistance to microbial breakdown which allows it to last longer (Bewley *et al*., 2012). Use of green material is not recommended due to the high moisture content and risk of harbouring Klebsiella bacteria, an environmental mastitis pathogen (Janni *et al*., 2007). Bedding that contains natural oils and extracts are also not recommended as they inhibit microbial activity and may cause adverse health effects such as abortion if consumed.

There are some potential alternatives for bedding in composting barns that are showing early success as a bedding material in other housing systems including ground Miscanthus. Miscanthus is a C4 perennial woody grass that can be grown on-farm over 15-20 years. Miscanthus has an advantage in that it contains fewer nutrients and has high cellulose and lignin levels which may restrict bacterial growth. On the other hand, ground Miscanthus has a large surface area and therefore large water holding capacity which may favour bacterial growth. When compared with straw, no differences in bacterial content was found. In addition, when scored for comfort cows showed immediate acceptance of the material without prior familiarity to the bedding (Van Weyenberg *et al*., 2015). Other bedding alternatives may also be suitable provided they have the following characteristics; good physical structure, good water absorption capacity, less than 25% initial moisture content, less than 2.5 cm long and able to withstand tillage (Shane *et al*., 2010).

Compost Management

Proper management of composting barns is essential for the system to succeed. The most critical component of the barn is the bedding and in particular ensuring it remains a dry and comfortable lying surface at all times (Bewley *et al*., 2012). Wet bedding will reduce cow cleanliness, increase somatic cell counts and mastitis as well as reduce composting efficiency (Eckelcamp *et al*., 2017). Proper composting relies on micro-organisms to decompose organic matter and provide carbon dioxide, water and heat. The general concept of composting in the barn is mixing a carbon source, in this case the bedding, with manure and urine which is high in nitrogen, while providing aeration to encourage air infiltration and maintain moisture levels to allow for rapid breakdown of organic matter by microbes (Bewley *et al.,* 2012). Aeration enhances aerobic activity which generates heat and also mixes the manure and urine into the bedding to provide a fluffy, dry surface for the cows to lie on (Janni *et al*., 2007). Typically, aeration is completed by tilling twice a day while the cows are out being milked through the use of a modified cultivator or utility tractor with a harrow attached. Minimum tillage depth for sufficient aeration ranges between studies from 20 – 30 cm (Bewley *et al*., 2012; Eckelcamp *et al.*, 2017; Janni *et al*., 2007). It is important to avoid over compaction of the bedding through the use of heavy equipment as this will increase internal moisture, reduce aeration and prevent a dry and fluffy surface from being created.

The internal temperature of the bedding will provide a good indication of the level of microbial activity. Measurements should be taken 15 – 30 cm below the bedding surface to avoid ambient air temperature affecting the reading. The ideal temperature should be between 40 and 60°C for proper composting, (Barberg *et al*., 2007; Bewley *et al*., 2012). At lower temperatures of approximately 35 - 40°C, microbial populations become more diverse and less efficient at degrading bedding material (Black *et al*., 2013), causing a slowing of the composting process. In contrast, temperatures above 65°C will become uncomfortable for cows to rest on and may also kill beneficial bacteria (Bewley *et al*., 2012*)*. Janni *et al.* (2007) suggested that pathogens can be inactivated by maintaining high temperatures of 54 - 65°C for 3 to 4 days, however, Barberg *et al.* (2007) showed that internal bedding temperatures did not get high enough for inactivation of pathogens to occur. This was confirmed in a study by Eckelcamp *et al*. (2016) of eight Kentucky composting barns who found all bacteria concentrations, except for coliforms, decreased with increasing internal bedding temperatures but did not kill them completely. Coliforms showed a moderate increase in response to increasing temperature (Fig. 2.2).

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Figure 2.2 Relationship between compost bedded pack temperature (^{o}c) at a depth of 20 cm and bedding bacterial counts in 8 Kentucky composting barns between May 2013 to May 2014. Retrieved from Eckelcamp *et al*. (2016).

Management of moisture content is important to enable proper composting and prevent the bedding from turning to sludge. Moisture enters the bedding through manure and urine as well as from microbial activity, although in poorly designed barns water can also enter during rainfall events. The ideal range for moisture content varies between research but is typically around 40 – 55% (Bewley *et al*., 2012; Black *et al*., 2013; Janni *et al.* 2007). Below this level microbial activity will be limited by lack of moisture thereby slowing the composting process. Above 40 – 55% composting will become anaerobic reducing decomposition rate and heat generation. In addition, excess moisture will cause bedding to stick to the cows resulting in reduced cleanliness and increased risk of mastitis infections (Bewley *et al*., 2012; Eckelcamp *et al*., 2016). Managing moisture content during winter can be more difficult than summer due to greater ambient moisture levels. As such, bedding additions in winter are often more frequent to help keep cows clean and dry by reducing moisture content. In a study of 47 farmers, Black *et al.* (2013) recorded that bedding additions in winter were required every 16.4 days, however, there was a large range in producer responses to wet weather with some adding bedding every day and others adding bedding every 56 days. Comparatively, summer weather lengthened the interval between bedding additions to a mean of 18.2 days, although the range was large and varied from every other day to every 45 days. Eckelcamp *et al*. (2016) suggested that the heat of composting in summer combined with higher ambient temperatures allowed the bedding to dry quicker thereby prolonging the interval between bedding additions.

Typically, 100 – 200 mm of bedding is added every 1 – 6 weeks but will be affected by the amount of manure and urine produced, ambient humidity, temperature and season (Janni *et al*., 2007). The best time to add new bedding is when moisture levels exceed 55% but before it reaches 60%. At 60% or above the bedding begins to adhere to cows and at this stage it is too late to add new bedding as the pack is already in a deterioration stage (Eckelcamp *et al*., 2017). Using a moisture probe is the most accurate way to test moisture content however, a simple 'ball' test can also be used to estimate moisture levels by squeezing a handful of bedding into a ball with your hand. If the ball falls apart when your hand opens the moisture content is below 40%. If you can bounce the ball on your hand and then it falls apart then it is approximately 55%. If the ball can be bounced and falls apart in chunks, doesn't fall apart or moisture can be squeezed out then moisture levels are above 60% and it is too wet (Eckelcamp *et al*., 2017; Janni *et al*., 2007). In addition to new bedding, reduced cow numbers and/or increased tilling will help with drying and aeration (Bewley *et al*., 2012).

Stocking density has a major impact on moisture levels and can be measured by the amount of space in the resting area that is available per cow. If the stocking rate is too high, then the increased manure and urine volume will reduce composting efficiency causing deterioration of the pack, increased somatic cell count and risk of environmental mastitis. Janni *et al*. (2007) recommended a minimum of 7.4 m^2 per cow for 540 kg Holstein-Friesians or 6.0 m^2 per cow for Jerseys. This is less than the 9.2 m^2 per cow quoted by Eckelcamp *et al*. (2017) and Bewley *et al*. (2012) for Holsteins and 7.9 m^2 per cow for Jerseys (Bewley *et al*., 2012). Fregonesi and Leaver (2001) noticed that lying time and rumination time per cow increased by 7 and 11%, respectively, when large resting spaces of 10 m^2 per cow were given compared to freestall barns. When this space is decreased to 9.2 m^2 no differences were found. In New Zealand and under duration-controlled grazing it is possible that the space per cow could be somewhat reduced.

2.3 Incorporating Composting Barns into New Zealand Dairy Systems

2.3.1 New Zealand Production Systems

In comparison to North American and European dairy systems where cows tend to be housed indoors year-round and fed a total mixed ration (TMR) diet, New Zealand dairying is characterised by its pasture-based, low-cost system (Pangborn, 2012). The ability to match pasture supply with animal demand can be difficult especially when adverse weather conditions, particularly drought, limits the ability of pasture to supply sufficient feed. Over the last few decades, the occurrence of droughts has become more frequent causing feed deficits and reduced production and is projected to increase with farms in most North Island and eastern South Island regions spending approximately 5-10% more of the year in drought by 2050 (NIWA, 2011). The ability to reduce impacts of feed deficits on milk production using imported feed has been one of the key drivers for the increased trend in supplementary feed use as well as the use of feeding facilities (i.e. feedpads). Other drivers include greater accessibility to low cost feed supplements, such as palm kernel expeller (PKE) and the ability to increase milk production (Mounsey, 2015).

The degree to which individual farms rely on pasture differs substantially within New Zealand and farms can be categorised into one of five production systems based on the level of supplementary feed used (Table 2.1; DairyNZ, 2017b). Supplements can be defined as any feed that is fed in addition to grazed pasture.

Table 2.1 New Zealand dairy five production systems. Adapted from DairyNZ (2017b).

		Five Production Systems
Low	System 1	All grass self-contained with all stock on the dairy platform. No supplement fed to the herd except supplement harvested off the milking area.
	System 2	Feed imported for dry cows. Approximately 4 – 14% of total feed is imported. Most of the cows are wintered off.
Medium	System 3	Feed imported for dry cows and to extend lactation (typically autumn feed). Approximately 10 – 20% of total feed is imported.
High	System 4	Feed imported for dry cows and used at both ends of lactation. Approximately 20 – 30% of total feed is imported onto the farm.
	System 5	Imported feed used all year, throughout lactation and for dry cows. Approximately 25 – 40% (but can be up to 55%) of total feed is imported.

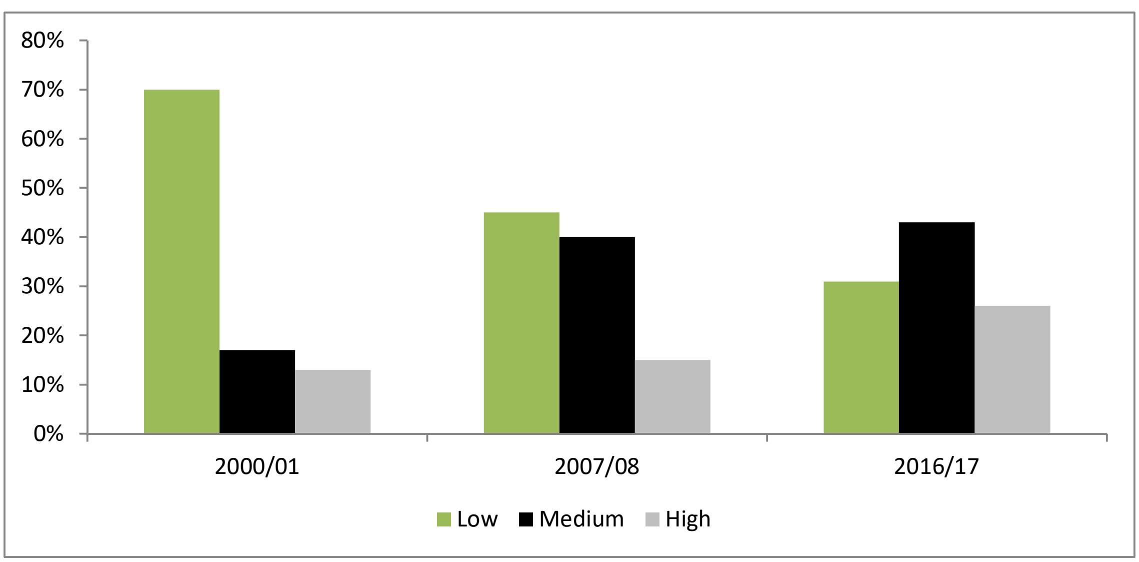

Figure 2.3 Per cent of New Zealand owner-operated herds in low, medium and high production systems in 2000/01, 2007/08 and 2016/17. Adapted from Mounsey (2015) and DairyNZ (2008, 2017).

Over the past 20 years dairy farms have shown a trend for increased use of supplementary feed. In the 2000/01 season, 70% of owner-operated dairy farms could be classified as low input (system 1 and 2), while only 17 and 13% of farms could be categorised as medium (system 3) and high input (system 4 and 5), respectively. In the most recent DairyNZ Economic Survey (2017a) these figures have changed to show that the majority of farms are now classified as medium input (43%), while the number of low input farms has declined to 31% with high input farms increasing to 26% (Fig. 2.3; DairyNZ, 2008, 2017a; Mounsey, 2015).

As a result of increased supplementary feed use some farmers have utilised feeding facilities (i.e. feedpads) to reduce wastage and the costs associated. The amount of feed utilised depends on the type of feed, feeding method, infrastructure and management practices used. In general, feedpad or housing facilities with designated feeding areas provide the greatest level of feed utilisation with wastage approximately 10% of the total feed offered. In comparison, 20% of feed is wasted when fed on pasture and increased to 40% when fed on pasture in wet conditions. Use of in-paddock trailers will reduce feed wastage to 15% (DairyNZ, 2017b). The incorporation of composting barns with feed alleys therefore has the potential to fit well into New Zealand dairy systems, particularly those that operate at a medium or high production system.

2.3.2 Climate

New Zealand is classified as having a temperate maritime climate with high sunshine hours making it ideal for growing C3 pastures such as perennial ryegrass. However, the climate experienced varies across regions with a warmer subtropical climate felt in the far north to cool temperate climates in the far south (NIWA, 2001). In general, New Zealand's climate allows cows to be grazed outdoors all year round without the risk of animals suffering from cold stress (Bryant *et al*., 2007). Young (1981) and Broucek *et al*. (1991) showed cows were more tolerant of cold than heat with a lower critical temperature of approximately -30^{o}c in dry, still conditions. Wind and rain will increase the critical temperature for cold but will still only affect cows in New Zealand for 1-3% of the year (Bryant *et al*., 2007; Young, 1981). Hot conditions in New Zealand however have been shown to affect milk production in Holstein Friesian (HF), New Zealand Jersey (NZJ) and crossbred (½ HF and ½ NZJ; HF x NZJ) cows.

In a study by Bryant *et al*. (2007) reductions of over 10 g of milksolids per day occurred in HF, HF x NZJ and NZJ cows when the temperature-humidity index (THI), a measure of 'hotness' based on combining temperature and humidity measurements, reached 68, 69 and 75, respectively (Fig. 2.4).

A THI of 68 and 75 is approximately equivalent to 21 and 25.5°c, respectively, at 75% humidity. In the northernmost regions of New Zealand heat conditions causing stress to HF cows may occur for 17-20% of the year. At a high THI, milk fat and protein levels are reduced. High genetic merit cows were also shown to be more susceptible to heat than low genetic merit cows due to more metabolic heat generated from milk production.

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Figure 2.4 The effect of temperature-humidity index (THI) on milksolids yield in Holstein-Friesian (HF; solid line), crossbred (HF x NZJ; dashed line), and New Zealand Jersey (NZJ; dotted line). Adapted from Bryant *et al.* (2007).

Heat stress occurs when a combined accumulation of heat gained from the environment and metabolic processes (West, 2003) exceeds heat lost by radiation, convection, evaporation and conduction (Kadzere *et al*., 2002). In response to heat stress, cows reduce their feed intake and consequently milk production. The heat threshold in New Zealand tends to be lower than other countries due to greater solar radiation levels (McKenzie *et al*., 2001), higher levels of exercise from long distances walked to and from the dairy shed (Tucker *et al*., 2005) and a diet of grazed pasture that may elevate heat production compared to concentrate diets (West, 2003). It is important to consider that the study conducted by Bryant *et al*. (2007) did not take into account the effect of hot periods on pasture availability and quality which may have had a confounding effect on milk production. As such, further New Zealand trials are required to understand and quantify the effects of hot conditions on dairy cows.

In any case, studies (Kendall *et al*., 2006; Laven & Holmes, 2008; Verkerk *et al*., 2006) have shown that shade provided by housing facilities provides significant benefits to animal welfare by reducing heat stress, provided the housing design is correct and does not exacerbate heat stress (West, 2003). In addition, barns are usually built near the dairy shed which reduces the distance that must be walked under hot conditions (Verkerk *et al*., 2006) and can be used as a stand-off area in wet conditions during winter to reduce pugging of pastures. Laven and Holmes (2008) also reported that in inclement conditions cows actively chose to enter housing rather than remain on pasture. As such, the use of composting barns may fit well in New Zealand dairy systems in respect to an animal welfare and pasture management viewpoint.

2.3.3 Management

Incorporation of composting barns in New Zealand dairy systems requires a transition from the traditional year-round grazing concept to an indoor-outdoor hybrid system with duration-controlled grazing. Literature on management of hybrid systems, particularly those utilising composting barns, is limited. However, anecdotal evidence from case studies of dairy farms that have incorporated housing structures into their systems has shown a greater focus on feed and pasture management after the transition from a pasture-based to a hybrid system (MPI, 2016a, 2016b, 2016c). Efficient utilisation of housing structures on three cases study farms throughout New Zealand appears to centre around fully feeding the cows, minimising feed wastage and maximising pasture quality. All three farms utilised duration-controlled grazing to reduce pugging damage and environmental impacts in autumn and winter, and to improve cow comfort during adverse weather (i.e. rain, snow, heat). On one farm this involved pasture grazing for 14 hours, eating at a covered feedpad for eight hours and milking for the remaining two hours.

The balance between dry matter supplied as pasture and supplementary feed differed between farms and was dependent on farm physical properties (i.e. soil type, climate) and farmer preference, but in general use of supplementary feed increased to take advantage of off-paddock feeding facilities, reduce the impact of pasture deficits, maximise cow intake and increase production. This was consistent with a study by Journeaux and Newman (2015) which found supplementary feed increased by approximately 1 – 2 t DM/cow with subsequent increases in milk production reported at between 6 – 38% after the incorporation of housing structures on farm.

2.3.4 Economics

While no studies to date have investigated the impact of composting barns on a New Zealand farm's financial performance, extrapolations can be made from similar studies using other housing types. Journeaux (2013) investigated the financial, as well as environmental, performance of a range of winter housing structures including free stall barns, herd homes and covered deep litter standoff pads. The results of the study were problematic in that to increase economic viability, which was dependent on payout and supplementary feed costs, improvements in environmental performance had to decline. Thus, the conclusion was that either the barns could improve the economic or environmental outcomes of the farm business but not both. In contrast, a similar study by de Wolde (2006) comparing indoor wintering with outdoor wintering in Southland reported favourable economic outcomes for the housed system as well as reduced nitrogen leaching. It is possible that the capital cost of the structures were responsible for the differing outcomes. de Wolde (2006) used a figure of $1,500 per cow for a freestall barn while the average housing cost used in the study by Journeaux (2013) was $2,000/cow.

The key change in costs that were associated with the addition of housing facilities on farm reported by Journeaux (2013) were the cost of the facility and effluent disposal, increased feed, labour and tractor costs and additional costs associated with increasing cow numbers and repairs and maintenance on the housing facility. On the other hand, the cost benefits included saved costs of not wintering cows off farm, reductions in fertiliser, and cost benefits associated with better cow condition, reduced dry cows, increases in pasture production, milk production and lactation length.

2.4 Animal Health and Welfare

Both internationally and in New Zealand there is a general perception that welfare of dairy cows grazed outdoors is far improved than for cows housed indoors (Loveridge, 2013). However, research from America has shown that housing cattle in composting barns year-round is animal-friendly and promotes greater welfare than other confinement systems, particularly those housing cattle on hard flooring (Haley *et al*., 2001; Herlin, 1997; Ofner-Schrock *et al*., 2015). In New Zealand, the ability to use composting barns in a hybrid system with regular access to pasture has the potential to have significant welfare benefits through the ability to provide shelter from extreme weather conditions (Laven & Holmes, 2008), while still providing cows with the ability to graze outdoors.

Outcome-based measurements including cow hygiene and the prevalence of lameness and mastitis can be used as indicators of animal health and welfare (Lobeck *et al*., 2011). In addition, behavioural activities and preference tests can also be used to identify welfare benefits (Fraser *et al*., 1993; Freganesi & Leaver, 2001).

2.4.1 Mastitis

Mastitis is the inflammation of the mammary gland in response to an infection by a mastitis-causing agent. It is a multi-factorial and complex disease that is a result of interactions between cows, microorganisms and the environment (Petrovski, 2007; Watts, 1988). In New Zealand and around the world mastitis is considered to be one of the leading economically important diseases to the dairy industry (Eckelcamp, 2014; Lacy-Hulbert *et al*., 2002; Petrovski, 2007; Petrovski *et al.*, 2009).

Several causative pathogens have been linked to mastitis with the most common pathogens in New Zealand usually Gram-positive bacteria including *Streptococcus uberis, Staphylococcus aureus,* coagulase-negative staphylococci and *Corynebacterim bovis* (Lacy-Hulbert *et al*., 2002; McDougall, 1998). While these pathogens can be problematic overseas it is commonly Gram-negative bacteria such as *Escherichia coli* and Klebsiella species that are associated with mastitis (Lacy-Hulbert *et al*., 2002) in the Northen Hemisphere. The differences in mastitis-causing pathogens between countries is typically due to a combination of nutritional and environmental factors. In housed herds using total mixed ration (TMR) diets coliform mastitis is more common (Eberhart *et al*., 1987; Lacy-Hulbert *et al*., 2002) whereas in grazed herds in New Zealand and Australia or when cows are confined to organic bedding material (i.e. straw) mastitis is more commonly a result of streptococcal bacteria (Bramley, 1982; Lacy-Hulbert *et al*., 2002; Pankey, 1997).

Research by Lacy-Hulbert *et al.* (2002) explained that the reason for greater coliform mastitis in TMR systems may be a result of confinement of cows to a restricted area combined with higher coliform bacteria in faecal matter. This confirms findings by Huntington (1997) who reported that diets with high concentrations of starch can encourage *E*. *coli* growth in the large intestine which is subsequently excreted in the faecal matter. In addition, considerable increases in the milk production of cows on TMR diets compared to grass also affected the aetiology and increased the incidence of mastitis. It was concluded that the environment associated with TMR diets had a large effect on the incidence of clinical mastitis (Lacy-Hulbert *et al*., 2002) and therefore the cleanliness of the environment and cow hygiene had a large impact on the incidence of mastitis within a dairy herd.

A model developed by Reneau *et al*. (2005) assesses the hygiene of an animal based on leg and udder cleanliness using a five-point grading system whereby 1 = clean and 5 = dirty. Dirtiness of the udder and lower rear legs proved to have a significant effect on somatic cell count (SCC), with a one unit change in hygiene score having an approximate 40,000 – 50,000 cells/mL change on herd SCC. The majority of somatic cells are white blood cells which increase in the milk as an immune response. Mastitis infections therefore cause the SCC to increase and act as an indicator for the development of mastitis within a cow (Schukken *et al*., 2003). Herds with a bulk milk SCC (BMSCC; concentration of somatic cells present in the vat or bulk milk) of ≤300,000 cells/mL indicates that for each 100,000 cells/mL approximately 15% of cows within the herd are infected with mastitis. At 400,000 cells/mL and over, New Zealand dairy companies will begin grading the milk supply of farms, giving demerit points and financial penalties depending on the severity and period of grading (DairyNZ, 2013a).

Shane *et al.* (2010) compared the effectiveness of different bedding types for composting barns and found sawdust and a woodchip/sawdust mix had a hygiene score of 2.4 and 2.5, respectively. This was similar to Barberg *et al*. (2007) who found that composting barns did not negatively affect cow hygiene with a mean score of 2.66 $\pm$ 0.19 and a SCC of 325,000 $\pm$ 172,000 cells/mL which was below the state average of 357,000 cells/mL. In addition, it was found that six out of the nine farms studied had a reduction in herd mastitis infection rates of between 27.7% - 35.4% after moving to a composting barn from other housing facilities. Only one farm had an increase in their mastitis infection rate of 3.6% (Fig. 2.5). It was suggested that the practice of tilling the bedding twice daily to aid with aeration and drying of the surface may have helped to achieve greater conditions for improved udder health and cleanliness (Barberg *et al*., 2007).

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Figure 2.5 Average mastitis infection rate for nine herds before and after being housed in a composting barn. Grey = average mastitis infection rate prior to composting barn housing; black = average mastitis infection rate after shifting to composting barns. *P < 0.05. Retrieved from Barberg *et al*. (2007).

In comparison, Lobeck *et al*. (2011) compared the hygiene of composting barns with freestall barns and found cows housed in composting barns had higher overall hygiene scores (3.18), indicating dirtier animals, than freestall barns (2.77; Table 2.2). This was higher than the scores found by Barberg *et al*. (2007) and Shane *et al*. (2010). No clear explanation for the differences in hygiene score between the three experiments could be found. However, farmers reported that management of the bedding at an optimal moisture and temperature was more difficult in wet conditions and this was reflected with higher overall hygiene scores in winter (3.33) than in summer (3.21; Lobeck *et al*., 2011; Table 2.2). This is consistent with Eckelcamp *et al.* (2017) who found that at a higher moisture content, bedding material appeared to adhere to cows more easily thereby reducing herd cleanliness. It was suggested that greater frequency of bedding additions in winter may help improve management of moisture content at an optimal range during this time (40% – 65%; Shane *et al*., 2010; NRAES-54, 1992).

However, despite the higher hygiene score reported by Lobeck *et al*. (2011) no differences in the prevalence of mastitis between composting and freestall barns was found. This coincides with Barberg *et al*. (2007) and indicates that composting barns do not negatively affect cow hygiene or the incidence rate of mastitis when compared with other housing systems.

Table 2.2 Least square means (LSM) and standard error (SE) of hygiene scores in composting barns (CB), cross-ventilated freestall barns (CV), and naturally ventilated freestall barns (NV) in Minnesota and eastern South Dakota. Adapted from Lobeck *et al*. (2011).

	Housing System					
	CB		CV		NV	
	LSM	SE	LSM	SE	LSM	SE
Winter	3.33^{a}	0.13	2.71^{byx}	0.09	2.78^{b}	0.09
Spring	2.95	0.13	2.67^{y}	0.09	2.66	0.09
Summer	3.21	0.13	3.05^{x}	0.09	2.84	0.09
Autumn	3.22	0.13	2.87^{xy}	0.09	2.82	0.09

$^{a,\,b}$ Significant differences among columns (housing type) within season ($P < 0.05$).
$^{x,\,y}$ Significant differences among rows (seasons) within housing systems ($P < 0.05$).

Very few, if any, studies have compared cleanliness and mastitis levels in composting barns compared to grazing systems and certainly no studies to date have compared this in the New Zealand environment. Previous research from America and the United Kingdom using free stall barns has however shown that cows on pasture tend to have greater hygiene, as reflected in the incidence rate of mastitis and SCC levels, compared to those in barns. Washburn *et al.* (2002) found cows housed in free stall barns had 1.8 times more clinical mastitis and eight times the rate of culling for mastitis than cows on pasture. Furthermore, Goldberg *et al.* (1992) found lower udder health problems in grazing herds compared to housed herds and Ellis *et al.* (2007) reported cows were dirtier when indoors than when they were on pasture. In saying this, it is important to note that cow hygiene and mastitis in pasture systems can be poor and is dependent on milking practices and climatic and environmental conditions. Similarly, cow hygiene can be good in well-managed housing systems. It is possible that the incorporation of a composting barn into a pasture system may increase cow hygiene by providing a ‘stand-off’ area for cows during wet and muddy conditions. Further research in this area is required to understand the implications of incorporating composting barns into a hybrid system with pasture grazing.

2.4.2 Lameness

Lameness is a multifactorial disease caused from interactions between the environment, nutrition, and management (Hedges *et al*., 2001). Dairy cow lameness impacts on cow health and productivity (Chawala *et al*., 2013; Hedges *et al*., 2001) and is a significant welfare and economic issue in the dairy industry worldwide. In New Zealand, the prevalence of lameness is approximately 30 – 50% of that in countries where cows are housed indoors (Laven & Holmes, 2008) and the aetiology of the disease differs considerably.

Digital dermatitis and sole ulcer are rare forms of lameness in New Zealand (<2%; Chesterton *et al*., 2008; Somers *et al*., 2005) but account for up to 40% of lameness in housed cattle in the United Kingdom (Laven & Holmes, 2008). Chesterton *et al*. (2008) found that in New Zealand white-line disease, sole injury, footrot and axial wall lesions were the major forms of foot lesions and accounted for 93% of lameness cases, but only accounted for 66% of lameness in dairy herds in the UK (Hedges *et al*., 2001). In a separate study by Somers *et al*. (2003) the most common form of lameness in straw bedded packs (similar to composting barns) was white line disease with 5.5 and 4.7 times greater risk than pasture or housed herds. Conversely, digital dermatitis and sole haemorrhages was lowest in straw bedded packs at 0% and 28.8% compared to 24.4% and 41.2% in housed herds and 27.6% and 54.1% in pasture herds, respectively. It is therefore possible that the introduction of composting barns in New Zealand may change the prevalence and aetiology of lameness presented in dairy herds, although this will likely depend on the amount of time spent in the barn per day (Rutherford *et al*., 2008).

The incidence of lameness in housed herds is dependent on a range of factors including housing type, bedding material, flooring design and diet (Adams *et al*., 2017; Eckelcamp, 2014; Hernandez-Mendo *et al*., 2007; Laven & Holmes, 2008; Smits *et al*., 1992). Softer flooring reduces lameness rates as it deforms under pressure which increases the contact area and dampens the force impact on the knees and hooves (Dumelow, 1995). This is consistent with statements from Hernandez-Mendo *et al.* (2007) which suggested that cows on pasture tend to benefit from reduced lameness due to being on a more comfortable surface for lying and standing compared with freestall barns. Therefore, comfortable housing, such as that provided by composting barns, may improve hoof health by providing a more appropriate bedding material for both standing and lying (Cook *et al*., 2004). This can be confirmed by several studies (Adams *et al*., 2017; Barberg *et al*., 2007; Lobeck *et al*., 2011; Ofner-Schrock *et al*., 2015) which showed that composting barns reduced lameness rates in cows in comparison to other housing systems and was likely a result of the open barn design and use of soft, organic bedding. It is possible that in New Zealand where lameness rates are increased by the distance walked to and from the milking shed and paddock (Chesterton *et al*., 2008) that housing cattle in composting barns will reduce lameness by not only providing a soft surface but by also reducing distances travelled.

Barberg *et al*. (2007) found that the average incidence of lameness in 12 composting barns in Minnesota was reduced to 7.8% of the herd when compared with 25% in freestall systems. This was comparable to Lobeck *et al*. (2011) who found lameness was lower in composting barns (4.4%) than naturally ventilated freestall barns (15.9%). It was hypothesised that the reduction in lameness prevalence was due to cows spending less time standing on concrete and did not have any restrictions when lying or standing. This is confirmed by Vanegas *et al*. (2006) who found cows housed on concrete were five times more likely to develop some form of lameness than herds housed on a softer rubber matting surface. Similarly, cows on deep sand bedding showed a lower incidence of lameness than those on mattress-bedded stalls (Cook, 2004). Overall, studies have shown that composting barns, independent of bedding material, provide an environment that results in good leg health and low lameness rates (Barberg *et al*., 2007; Lobeck *et al*., 2011; Shane *et al*., 2010).

2.4.3 Cow Behaviour and Preference

Composting barns do not include the stalls and partitions that are found in freestall barns and instead provide cows with an open resting area that maintains cow health and welfare (Klaas *et al*., 2010) and allows the expression of natural behaviours (Endres & Barberg, 2007). Lying behaviour is a high-priority activity (Metz, 1985) with cows spending 8 – 16 hours a day lying down (Haley *et al*., 2001). Deprivation of lying causes abnormal behaviours indicative of frustration and stress (Krohn & Munksgaard, 1993). In a study of 12 composting barns in Minnesota, Endres and Barberg (2007) found that the barns did not restrict the lying or lunging area for cows, provided sufficient stocking density was given, and allowed cows to exhibit all the natural lying positions without disturbance or obstruction. Play behaviour (mock fleeing, mock aggression and environmental exploration) was also seen immediately after cows were moved from freestall housing to a bedded pack barn, indicating greater psychological and physical welfare (Fregonesi & Leaver, 2001).

Cow preference tests can be used as a means of identifying features of a housing system that is important to them and can give a strong insight into how animals rank different options provided (Fraser *et al*., 1993). Previous research has shown that dairy cows have a strong preference for lying (Tucker *et al*., 2003) and standing (Freganesi *et al*., 2009) on softer and drier surfaces such as that provided by composting barns. In addition, when offered a choice between freestalls and bedded packs, cows chose to spend more time in the bedded pack and increased their lying time by an extra 1.34 hours per day (Freganesi *et al*., 2009).

Phillips and Schofield (1994) noted that oestrus behaviour increased in bedding packs compared to freestalls. Such activities including standing to be mounted (0.48 vs 0.42), mounting without standing (0.36 vs 0.30), successful mounting (0.54 vs 0.36), chin rubbing on rump (0.30 vs 0.24) and sniffing or licking of the genital area (0.30 vs 0.18). Consequently, in-calf rates after the first service increased from 55% in freestalls to 90% in composting barns. This is consistent with Barberg *et al*. (2007) who reported increased pregnancy rates after transitioning cows into a composting barn.

2.5 Environment

Whist the New Zealand dairy industry is striving to meet the increased global demand for dairy products, farmers are required to lower their environmental footprint and meet tightening regulations set by Regional Councils (Parminter, 2015). Improved water quality is a key aim for the New Zealand government with nitrate leaching losses from agriculture, particularly dairy, being at the forefront of discussions. Under the New Zealand government's National Policy Statement for Freshwater Management (MfE, 2017) several regional councils have implemented restrictions on the amount of nutrients, particularly nitrogen (N), that is able to be leached from a farming system. Increasingly, greenhouse gas emissions (GHG) are also becoming an area of concern with the New Zealand government setting a target of reducing total GHG emissions to 5% below 1990 levels by the year 2020 (MfE, 2018a). To be able to achieve these targets and improve New Zealand's agricultural sustainability, new strategies are required that will not only lower farming's environmental footprint but maintain or increase production and animal welfare. Composting barns may provide part of the solution with much of the environmental benefit coming from the ability to operate duration-controlled grazing whereby cows are kept off pasture for a period of time to minimise nitrogen leaching as well as reduce pasture pugging (Christensen *et al*., 2018b). In addition, it is possible that with feeding areas within the barn increases in feed conversion efficiency may also reduce greenhouse gas production per kilogram of milk produced (FAO, 2013). No known studies have measured nitrate leaching in duration-controlled grazing systems using composting barns, however a few studies have investigated the potential to use duration-controlled grazing in New Zealand (Christensen *et al*., 2018a, 2018b; Monaghan *et al*., 2007).

2.5.1 Nitrate Leaching

Grazed pasture systems have a high potential for nitrate (NO_3^-) leaching. This is because only a small fraction of the N consumed by grazing animals is removed in the product with 60 – 90% returned to the soil as animal excreta (Jarvis *et al*., 1995). Over 70% of the N in excreta is in the form of urine with 70 – 90% of urinary N in the form of urea (Hayes and William, 1993). Cows urinate approximately 10 – 12 times a day creating small (0.5 – 0.7 m^2) but highly concentrated urine patches (1000 kg N/ha). Some of this N is volatilised, however the majority undergoes nitrification by soil microbes. At such a high loading rate, plants are unable to utilise all the nitrate creating a high potential for leaching during rainfall events. This is because nitrate, like temperate soils, is negatively charged and hence is not retained in the soil profile allowing it to easily leach into groundwater. Often the high NO_3^- loading rate in urine patches is exacerbated by N fertiliser applications and waste effluent that is used to overcome pasture N deficiencies (Di & Cameron, 2002). Di and Cameron (2002) showed that annual N leaching losses from a paddock that had 25% of the area covered by urine patches would be approximately 33 kg N/ha, provided no other fertilisers or waste effluent applications were used. This was based on a study (Silva *et al*., 1999) that showed the NO_3-N concentrations in the drainage water below a urine patch reached 120 mg NO_3-N/L. When urea or dairy shed effluent was also applied at rates of up to 400 kg N/ha the annual N leaching loss increased to 36 – 60 kg N/ha.

The removal of cows from pasture in a duration-controlled grazing system reduces the quantity of urine patches deposited onto pasture (Christensen *et al*., 2018b). Thus, the N leaching potential is reduced (de Klein & Ledgard, 2001). This could be achieved by shifting cows into stand-off facilities, such as composting barns, to ruminate and rest after grazing for a short period of time. The excreta that is produced in the barn would compost with the bedding to create a fertiliser that can be applied to pasture at a later time and at a consistent rate. Understanding the time cows require for grazing to achieve the same level of milk production is critical to being able to operate this type of system effectively.

Christensen *et al*. (2018a) showed that cows grazing for only 4 hours between milkings could harvest similar amounts of pasture as cows grazing outdoors for the full period between milkings, and reduced excreta N by approximately 62%. As such, supplementary feeding in the barn is not necessarily required, although would likely lift milk production and feed conversion efficiency (FAO, 2013; Bargo *et al*., 2002). Additional feed costs would need to be quantified and investigated on a per farm basis to determine whether supplementary feeding would lift overall profitability. Given composting barns provide a high-quality animal welfare environment (Haley *et al*., 2001; Herlin, 1997; Ofner-Schrok *et al*., 2015), it is feasible for cows to remain inside the barn for 20 hours per day. Alternatively, cows could be stood-off pasture for longer periods of time during high-risk periods. A study by Shepherd *et al*. (2011) reported that on free draining soils in the Waikato between 40 – 56% of the urine deposited from February to May was leached from the root zone by the end of the winter drainage season while not all of the urine deposited during June and July was leached by the time drainage had completed in October. This supports the work by Christensen *et al*. (2018b) which demonstrated that grazing during the late summer and autumn period were important contributors to NO_3^- leaching during the drainage season (Fig. 2.6). In addition, this supports predictions made by de Klein and Ledgard (2001) that a reduction of 35 – 50% in NO_3^- leaching could be achieved when duration-controlled grazing was used in autumn compared to traditional grazing.

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Figure 2.6 Estimated urinary nitrogen not taken up by pasture (kg/ha) for duration-controlled (DC) and standard grazing (SG) from 2009 – 2011. (Autumn grazings = March – May; summer grazing = December – February; spring grazings = September – November) Retrieved from Christensen *et al*. (2018b).

2.5.2 Greenhouse Gas Emissions

In New Zealand, agriculture represents 49.2% of New Zealand's gross GHG emissions with methane (CH_4) and nitrous oxide (N_2O) being the two largest contributors. The dairy sector is responsible for the greatest amount of emissions compared to any other livestock sector in New Zealand with CH_4 from enteric fermentation and N_2O from manure (urine and dung) accounting for 35.2 and 14.2% of the GHG emissions from the agricultural sector, respectively (MfE, 2018b). Hence, a reduction in CH_4 and N_2O emissions are vital to any attempt in reducing New Zealand's GHG emissions. Composting barns may provide a solution through their ability to improve feed conversion efficiency (FCE) and reduce CH_4 and N_2O emitted from the bedded pack. However, very little data exists in this area and more research is needed to measure GHG production from composting systems.

Feed intake is the main driver of enteric CH_4 production. Improving the feed conversion efficiency of a cow will therefore reduce GHG emissions per kilogram of milk or milksolids produced. Beukes *et al*. (2010) stated that the key to reducing dairy's GHG emissions lies in maintaining milk production while reducing total feed consumption. High genetic merit cows with greater feed conversion efficiencies (83.4 $\pm$ 1.7 g MS/kg DM compared to 71 $\pm$ 0.5 g MS/kg DM) allowed production to be maintained at 430 kg MS/cow while dry matter intake decreased by 12.3%. Consequently, CH_4 emissions decreased by 17.0% from 348 g CH_4/kg MS to 289 g CH_4/kg MS. In addition, de Klein and Eckard (2008) showed that improved biological efficiencies also altered nitrogen partitioning with less N deposited in the urine leading to lowered N_2O emissions.

Optimisation of feed quality and composition is also critical and interrelated with dry matter intake in terms of reducing enteric CH_4 emissions. Balancing an animal's diet so as to match nutrient supply with animal requirement will inevitably maximise production and reduce GHG emissions per unit of animal product (FAO, 2013). Relatively few studies exist which compare TMR with pasture-based diets. Nonetheless, a study by Bargo *et al*. (2002) compared three feeding systems in lactating dairy cows; a pasture plus concentrate diet, pasture plus TMR (a partial TMR diet) and a complete TMR diet. Cows fed TMR consumed more feed and produced more milk than cows fed pasture or partial TMR. The FCE was greater for the TMR diet at 1.37 kg fat-corrected milk (FCM)/kg DMI compared to both the pasture (1.25 kg FCM/kg DMI) and partial TMR diet (1.23 kg FCM/kg DMI). The ability to supplement dairy cow diets with feed alleys in composting barns provides significant potential for optimisation of biological efficiency and reduction in greenhouse gas production, particularly enteric CH_4 production.

Methane, along with nitrous oxide (N_2O), is also produced during the decomposition of manure, mainly under anaerobic conditions (IPCC, 2006). Unlike intensively managed housing systems, such as freestall barns, animal manure in composting barns is not scraped away into effluent storage systems where anaerobes decompose manure producing CH_4 and N_2O, but rather it is left in place to be composted with the bedding. Daily tilling aids this composting by providing oxygen into the pack. As such, decomposition of manure is largely by aerobic bacteria rather than anaerobes thereby reducing GHG emissions. To date no known studies have quantified this reduction. After 6 – 12 months the composted material can be applied to pastures as a valuable fertiliser. A study in which composted material was applied to pasture showed that N_2O losses were negligible (0 – 0.3%). Hence, the current N_2O emissions from urine and dung which represent 14.2% of New Zealand's total GHG emissions from the agricultural sector (MfE, 2018b) could be significantly reduced if cows were to be housed in barns for considerable periods of time, up to 20 hours a day, by shifting excreta deposition from grazed pasture to the compost bedded pack.

Ammonia (NH_3) is an intermediary gas in the production of N_2O and is considered to be one of the most harmful gases produced by agriculture (Eckelcamp, 2014). In the Netherlands NH_3 emissions are restricted to 9.5 kg per cow per year and in the UK total ammonia emissions are limited to 297 kt of NH_3. To date, New Zealand has not set a maximum NH_3 limit, however Worksafe New Zealand (2018) recommends restricting workplace exposure to an eight-hour weighted average of no more than 25 ppm or 35 ppm for no longer than 15 minutes. Composting barns have been shown to produce NH_3 levels below these limits with Shane *et al*. (2010) and Klaas *et al*. (2010) reporting NH_3 levels of 3.9 and <0.5 ppm per day, respectively. Eckelcamp (2014) stated that ammonia emissions were greater when the C:N ratio of the bedded pack was below 25:1. In well-managed composting barns the C:N ratio should be between 25:1 to 30:1 for optimal composting (Bewley *et al*., 2012; Janni *et al*., 2007).

2.6 Summary of Literature Review

Composting barns have provided dairy farmers with improved cow management that has led to greater cow comfort and welfare. This in turn has lowered dairy lameness rates and, in many cases, reduced somatic cell counts when compared to other housing facilities. It is suggested that the use of composting barns in a New Zealand hybrid system with access to pasture may further reduce lameness and potentially mastitis rates, but this has not been directly studied with composting barns.

Current literature suggests that composting barns could be part of the strategy to reduce nitrogen leaching losses from New Zealand dairy grazing systems through the adoption of duration-controlled grazing, although further research and quantification is needed. Likewise, there is the potential for reduced greenhouse gas emissions through improved feed conversion efficiency and reduced deposition of dairy excreta on pasture but again research is urgently needed to confirm these suggestions.

The key constraints to the adoption of composting barns, besides a lack of literature, include the availability of woodchip and sawdust bedding and understanding of the management principles required. Alternative bedding options are available including ground Miscanthus which can be grown on-farm but its use in composting barns has not been documented. The barn design and management principles including daily tilling are key to the success of composting barns. Failure to understand these concepts will prevent a clean and comfortable bedding from being produced and will negatively affect animal health and welfare.

One of the key findings out of this literature review is the lack of information on composting barns surrounding areas besides compost management and animal welfare. If composting barns are to be adopted in countries, such as New Zealand, where housing cows is not traditionally practiced then urgent research is needed in the areas of environmental sustainability and incorporation and management of barn systems.

Chapter 3

Methodology

3.1 Research Approach

A mixed methods research approach (Creswell & Plano-Clark, 2006) was used to construct and model the two farm systems necessary to investigate the environmental and economic impacts of a composting barn on New Zealand dairy farms. The mixed methods approach allows quantitative and qualitative data to be collected, analysed and mixed in a single study to provide a better understanding of the research than either approach alone (Creswell & Plano-Clark, 2006). In this study, the two farm systems were referred to as 'without a composting barn' and 'with a composting barn.' The Lincoln University Dairy Farm (LUDF) was used as the base farm (without a composting barn) due to its proximity and availability of physical and financial data. A composting barn system was then modelled on this base system using information gathered from qualitative and quantitative sources. The use of Overseer® and Excel based modelling was then used to draw environmental and economic comparisons, respectively, between the 'with' and 'without' system.

3.2 Research Questions

1. What are the reasons for building composting barns in New Zealand?
2. How will a composting barn affect the production levels of a dairy farm?
3. What are the critical components of the composting barn system that will affect the economic success of a dairy farm?
4. What are the critical components of the composting barn system that will affect the nutrient leaching profile and greenhouse gas emissions on a dairy farm?
5. What are the key constraints to adoption of composting barns in New Zealand and can these constraints be overcome?

3.3 Data Collection

3.3.1 LUDF Base Farm

The base LUDF farm system was created from physical and financial records publicly available on the LUDF webpage (SIDDC, 2018). The most recent data from the 2017/18 season was used to create this base system to allow for the most accurate comparisons to be made. Financial data gathered was entered into Excel cashflow and investment return spreadsheets to determine the current financial performance of the LUDF without a composting barn. Key performance indicators (KPIs) including internal rate of return (IRR) and net present value (NPV) were generated using this data. All of the farm's nutrient budget and greenhouse gas emission figures were gathered from Overseer® records that had previously been created for the LUDF. Excel based feed budgeting models were also used to develop the initial feed budgets based off stock performance and pasture production.

3.3.2 Composting Barn System

The data required to create the composting barn system was collected from an existing New Zealand composting barn and from experts in the field. This included gathering insights from researchers surrounding the new feed system, construction company Calder Stewart to advise on composting barn design and costs, and general farm systems and cow housing experts to advise on the change in system. As with the base farm, financial data was entered into Excel spreadsheets to generate the KPIs and allow comparisons to be made. Similarly, the physical information from the new composting barn system was entered into Overseer® to compare the nutrient outputs and GHG emissions.

3.4 Environmental and Economic Models

3.4.1 Overseer®

Overseer® Nutrient Budgets (version 6.3.0) was an important tool used to measure the nutrient inputs and outputs of the LUDF with and without a composting barn. Overseer® is a farm-level decision support model that helps users develop annual farm nutrient budgets and test the environmental impact of farm management changes. The model is based off scientific principles that provide estimates of a farm's nutrient leaching profile in kilograms per hectare. In addition, Overseer® helps users identify the major sources of GHG emissions from farms based on the New Zealand Greenhouse Gas Inventory methodology (MfE, 2016), reporting on a per hectare and per product basis. The ability to use Overseer® to test management practices prior to and after the incorporation of a composting barn provided clear comparisons and allowed the critical components that affected the environmental outcomes to be identified.

It should be noted that Overseer® has a certain margin of error associated with its outputs due to necessary simplifications of complex processes (Shepherd *et al.*, 2013). However, Overseer® is currently the best software tool available for modelling nutrient cycles and GHG emissions from a farm system and is accepted for use by regulatory bodies. As such, Overseer® was considered the most appropriate tool for use in this research project but note figures should be used with caution when extrapolating data.

3.4.2 Microsoft Excel

Microsoft Office Excel 2016, a computer software programme, was a key tool used to analyse the financial performance of a composting barn system in comparison to a traditional New Zealand dairy farming system through the creation of monthly cashflows and a 20-year investment analysis (including depreciation and loan schedules). Monthly cashflow budgets allowed the impact of a composting barn on farm production and expenses to be determined while the investment analysis compared the long-term returns on investment. A twenty-year period was selected for the investment analysis as this provided sufficient insights into the viability of the system and changes.

Chapter 4

System Model

4.1 LUDF Current System

Formerly a sheep farm, the Lincoln University Dairy Farm was converted to a dairy unit in 2001 and is managed by the South Island Dairying Development Centre (SIDDC). The LUDF acts as a progressive development facility that is committed to advancing dairy farming practices across the South Island with a particular focus on productivity and environmental sustainability (SIDDC, 2018). Their strategic objective, as detailed on the LUDF webpage (SIDDC, 2018), is to maximise sustainable profit embracing the whole farm system through:

- increasing productivity;
- without increasing the farm's total environmental footprint;
- while operating within definable and acceptable animal welfare targets; and
- remaining relevant to Canterbury (and South Island) dairy farmers by demonstrating practices achievable by leading and progressive farmers.
- LUDF is to accept a higher level of risk (than may be acceptable to many farmers) in the initial or transition phase of the project.

It is believed that the incorporation of a composting barn on the LUDF has the potential to meet these objectives.

A physical and production summary of the LUDF is provided in Tables 4.1 and 4.2 below. The LUDF is a 186 ha property (160.1 ha effective) situated in Lincoln, Canterbury. Classified as summer dry and receiving an annual rainfall of 666 mm, the property is fully irrigated by a combination of two centre pivots, long laterals and K-line irrigators providing an extra 450 mm of moisture annually. The property has a range of soils ranging from free-draining stony soils to heavy and poorly-drained soils. Due to the large proportion of imperfectly and poorly-drained soils (50% of milking platform), winter soil management is challenging and must be carefully managed.

In the 2017/18 season the LUDF ran 558 Kiwicross cows at peak milking at a stocking rate of 3.5 cows per hectare. The farm produced 451 kg MS/cow (1571 kg MS/ha), putting them above the

Selwyn district average (417 kg MS/cow; 1367 kg MS/ha) for 2016-17 (DairyNZ, 2017c). However, the 2017/18 season was a below-average year due to poor weather conditions and reduced pasture quality. As such, the average milksolids production from the previous five seasons (2013/14 – 2017/18) of 485 kg MS/cow (1690 kg MS/ha) was used as the existing comparison base number. All cows are wintered off farm at Ashley Dene, a Lincoln University sheep research and wintering block, from mid-May through to late July, depending on calving date, at which time they are brought back to the neighbouring support block as springers. All replacement stock are also reared off farm at Ashley Dene.

Table 4.1 LUDF physical summary. Adapted from SIDDC (2018b).

Physical Summary	
Farm Area	
Total area (ha)	186
Milking platform (ha)	160.1
Support block (ha)	14
Climate	
Mean annual maximum temperature	32°c
Mean annual minimum temperature	4°c
Average days of screen frost	36 days per annum
Mean average bright sunshine	2040 hours per annum
Average annual rainfall	666 mm
Average annual evapotranspiration	870 mm
Average annual irrigation input	450 mm
Soil Type (% of milking platform)	
Free-draining shallow stony soils (Eyre soils)	5%
Deep sandy soils (Paparua and Templeton soils)	45%
Imperfectly drained soils (Wakanui soils)	30%
Heavy, poorly-drained soils (Temuka soils)	20%

Table 4.2 LUDF production summary. Adapted from SIDDC (2018b).

Production Summary	
Peak cows milked	558
Stocking rate (cows/ha)	3.49
kgMS sold	270,630
kgMS/cow	485
kgMS/ha	1,690
Herd average days in milk	264
Breed	Kiwicross
Live weight (kg)	480

4.2 Proposed Composting Barn System

The incorporation of the composting barns on the LUDF will allow stock to be removed from pasture during 'at-risk' periods, particularly during late autumn and winter when nitrate leaching is an issue. In addition, the housing facility will allow all cows to be wintered on-farm with cows spending up to 20 hours per day indoors with the remaining 4 hours spent outside grazing fodder beet and baleage. Replacement stock will still be reared off-farm at Ashley Dene.

In order to enable all cows to be wintered on farm, additional feed must be incorporated into the system to supplement pasture supply. This will include the use of fodder beet and grass baleage during the winter period and maize silage during the milking season to facilitate the proposed extended lactation, maintain cow condition and fill in pasture feed deficits.

The incorporation of a composting barn will affect the whole farm system and as such a number of assumptions must be made. System assumptions have been detailed in the below sections while the economic and environmental assumptions have been detailed in Chapter 4 and 5, respectively.

4.2.1 Composting Barn Design and Location

The proposed system will involve the construction of two composting barns near the milking shed based off an existing New Zealand composting barn in the Waikato with minor adjustments made (See Appendices A and B). Rather than having one large composting barn capable of housing 560 cows, it was decided that two smaller composting barns each capable of housing 285 cows would be built to allow for ease of management. No extra costs are associated with having an extra barn. The structure of the barn is essentially a covered loose-housing facility that has two sunken in resting areas (composting areas) in each barn separated by a central feed lane with feed troughs lining either side of the composting area. A concrete feed slab will separate the feed troughs and resting area to prevent feed and excess excreta entering the composting area. Excreta that is deposited onto the concrete can be scraped into the existing effluent management system. Each barn provides 5.6 m^2 of resting space per cow and 0.8 m^2 of feed alley space per cow. This is in less than the 7.4 – 9.2 m^2 of resting space per cow that was quoted in the literature review (Janni *et al*., 2007; Eckelcamp *et al*., 2017; Bewley *et al*., 2012) and is due to barn being operated as a hybrid system, rather than a year-round housing system where cows are housed in the barn 24/7.

Two alternative locations for constructing the composting barns are possible on the LUDF. The first is to situate the barns opposite the cowshed in paddock N-11 (see Appendix C), however the path of the centre pivot irrigator must be addressed with this location as it is not possible for the irrigator to go over the barn. For the purposes of this report, potential costs involved with altering the irrigator set-up have been ignored as this is a large uncertainty and is not relevant to many farms in New Zealand. Alternatively, the barns could be situated on the South Block in paddock S-9 with cows utilising the underpass to reach the cowshed. This would place the barn close to the silage pit and effluent pond and would also avoid issues with the irrigator but, would require the cows to travel further (approximately 150 m) to the milking shed. Both locations would require infrastructure to link the barns to the effluent management system. It is important to note however, that in a properly managed composting barn no effluent seeps out of the bedding, rather it is composted *in situ* and any additional liquid is evaporated away so that only effluent deposited onto concreted areas must be dealt with. Regardless, council regulation demands that the bedding area must be lined.

4.2.2 System Assumptions

Milksolids

With the incorporation of composting barns on the LUDF milksolid (MS) production was lifted by 100 kg MS/cow from 485 kg MS/cow (1690 kg MS/ha) to 585 kg MS/cow (2039 kg MS/ha). This resulted in an increase in overall milksolids production to 326,430 kg MS. The increase was assumed as a result of increasing the days in milk (DIM) to 305 from 264, better feeding regime, and less energy wasted on maintenance.

For comparison, the Allcock composting barn in the Waikato lifted milk production from 384 kg MS/cow prior to barn construction to 544 kg MS/cow in the third year of operation with the barn (2016/17) and was a direct result of increased per cow production. It should be noted that with the incorporation of the composting barn, the Allcock system moved from a system 2 to a system 5 with maize silage being the predominant feed used in the barn. In addition, the 20.6% increase in milksolids used in this study was within the 6 – 38% increase range reported by Journeaux and Newman (2015) after farmers incorporated housing structures on farm.

Days in Milk

Currently, the average days in milk (DIM) on the LUDF is 264. The incorporation of the composting barn will allow the lactation length to be increased as a result of housing the cows nearer the milking shed, providing shelter from the environment, reducing the amount of energy required for maintenance and providing a better feeding regime. It was assumed that the days in milk in the composting barn system would increase to 305 days, allowing for a recommended 60 day dry period (Coppock et al., 1974; Sorenson & Enevoldsen, 1991).

Replacement Rate

Due to better cow condition and feeding of cows in the composting barn system as well as reduced walking distances it is assumed that there will be a reduction in empty cows and animal health issues (i.e. lameness). As such, there is likely to be a reduction in the replacement rate and, in accordance to assumptions made by Journeaux (2013), was reduced by 2%. The replacement rate in the new system will therefore be a conservative 21% down from 23%.

Live weight

Cow live weight increased under the composting barn system from 481 kg to 500 kg to help facilitate the increase in milksolids production. While at the upper limit of the mature live weight for Kiwicross cows, it is assumed that the improved shelter and feeding conditions in the composting barn system will enable this target to be reached. While it may take several years for an average herd live weight of 500 kg to be achieved, for the purpose of this study, the time delay has been ignored.

Table 4.3 Production summary of the LUDF with and without a composting barn (CB).

Production Summary		
	LUDF (without CB)	LUDF (with CB)
Peak cows milked	558	558
Stocking rate (cows/ha)	3.49	3.49
Live weight (kg)	480	500
Herd average days in milk	264	305
Breed	Kiwicross	Kiwicross
kgMS/cow	485	585
kgMS/ha	1,690	2,039
kgMS/kg LW	1.01	1.12

Energy Requirements

Daily energy requirements for cows during lactation and winter were based off information published by Moran (2005) for a 500 kg housed cow with restricted access to outdoor grazing (Table 4.5, Fig. 4.1). Maintenance energy requirements were assumed at 54 megajoules of metabolizable energy (MJ ME) year-round, while energy for activity increased from 2 MJ ME during the dry period (June – July) to 4 MJ ME during lactation due to increased grazing time and walking to and from the dairy shed. Energy requirements for pregnancy were assumed negligible for the first five months of gestation following which 8, 10, 15 and 20 MJ ME were required for the sixth, seventh, eighth and ninth month of pregnancy, respectively.

It was assumed that cows would be dried off at a BCS of 4.5. Assuming the herd average increase in BCS required was 0.5 units to meet the 4.5 BCS target, and at 20 kg live weight gain per half unit increase in BCS with 40 MJ ME needed to increase weight by 1 kg in late lactation (Moran, 2005), an additional 13 MJ ME/day over the 60 days prior to dry off was required. In addition, assuming a target BCS of 5.0 at calving, a further 0.5 unit increase in BCS is required over the dry period. With an additional 15 MJ ME required to increase live weight by 1 kg during the dry period (Moran, 2005), then 37 MJ ME/d was required over the 60 day dry period for condition gain.

Energy for milk production (5.7 MJ ME/litre of milk) was also based off published data by Moran (2005) and assumed a milk fat and protein content of 4.5% and 3.5%, respectively. Average milksolid (MS) production was 1.9 kg MS/cow (585 MS per cow/305 days) with peak production assumed at 2.2 kgMS/cow. Energy required for milk ranged from 114 MJ ME in April to 157 MJ ME in October (Table 4.4).

Table 4.4 Monthly milksolids (MS/cow/day), litres of milk (L/cow/day) and energy requirements (MJ ME/cow/day) for milk production.

	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
MS/cow/day	2.0	2.1	2.2	2.1	2.0	1.9	1.8	1.7	1.6	1.7
Litres/cow/day	25.0	26.3	27.5	26.3	25.0	23.8	22.5	21.3	20.0	21.3
MJ ME/cow/day	143	150	157	150	143	136	129	121	114	121

Table 4.5 Daily energy requirements (MJ ME/cow/day) for a 500 kg housed cow with restricted access to outdoor grazing.

	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
Maintenance	54	54	54	54	54	54	54	54	54	54	54	54
Milk	143	150	157	150	143	136	128	121	114	121	-	-
Activity	4	4	4	4	4	4	4	4	4	4	2	2
Pregnancy	-	-	-	-	-	-	-	-	8	10	15	20
BCS gain	-	-	-	-	-	-	-	-	13	13	18	18
TOTAL	**201**	**208**	**215**	**208**	**201**	**194**	**186**	**179**	**172**	**202**	**89**	**94**

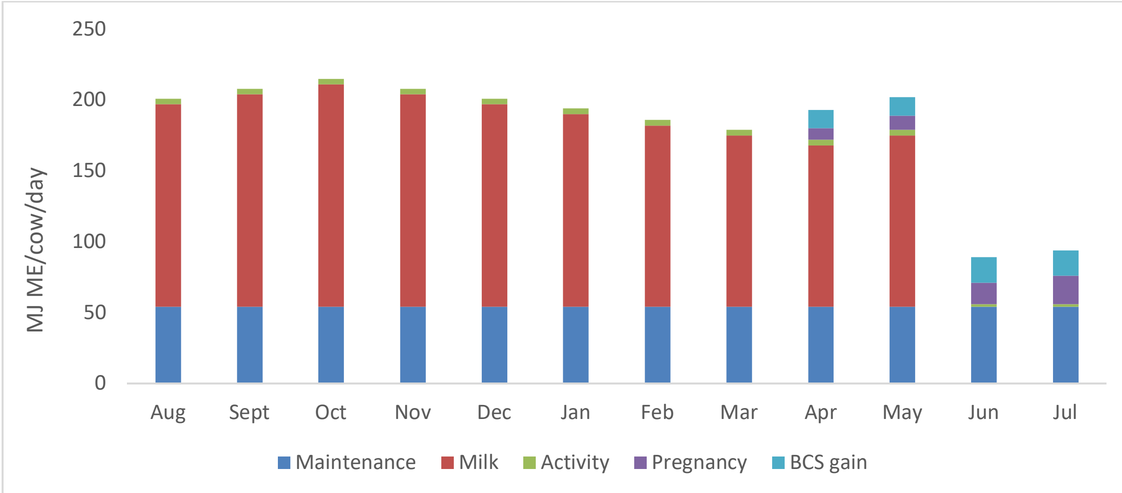

Figure 4.1 Breakdown of daily energy requirements (MJ ME/cow/day) for a 500 kg housed cow with restricted access to outdoor grazing.

Diet

Both the lactation and winter diet was altered with the incorporation of the composting barn on the LUDF and was created based on the energy requirements stated above. It was proposed that during the dry period cows would be fed a fodder beet and baleage ration during the daily four hour outdoor grazing period. Assuming fodder beet contains 12 MJ ME/kg DM and baleage contains 10 MJ ME/kg DM (DairyNZ, 2017b), then the daily feed ration for cows in June and July was assumed to be 6 kg DM of fodder beet per cow per day and 3 kg DM of grass baleage per cow per day totalling 102 MJ ME, slightly above their energy requirements (Table 4.6). Prior to feeding this ration, it is recommended that a 14-day transition period is used to slowly introduce the cows to fodder beet and reduce the risk of acidosis due to the high water soluble carbohydrate and low fibre content of the fodder beet. This transition diet will consist of starting the cows on 1 kg DM of fodder beet per cow per day with baleage used to supplement the rest of the cow's energy requirements. Every second day the fodder beet allowance can be increased by 1 kg DM, with baleage decreasing proportionally, until the required 6 kg DM is reached (DairyNZ, 2016b).

Total fodder beet consumed over this period equates to 174.6 t DM, including the transition diet. With 240 t DM of fodder beet grown (see *crop rotation* below) and allowing for 10% wastage (24 t DM) as published by DairyNZ (2013b) for grazed fodder beet, this leaves 41.4 t DM unallocated and available to be fed to early and late calvers (Table 4.7).

Total baleage consumed over the dry period equates to 109.2 t DM, including the transition diet and baleage required to supplement the remaining 41.4 t DM of fodder beet for early and late calvers. It is assumed that the baleage will be fed in the composting barn at 95% utilisation (DairyNZ, 2017b).

Therefore, to supply the 109.2 t DM necessary to meet cow requirements, 115 t DM of baleage will be needed. Total feed consumed during the dry period is equal to 330.6 t DM (0.71 t DM/cow; Table 4.7).

Table 4.6 Winter diet (MJ ME/cow/day (ME); kg DM/cow/day) based on metabolisable energy requirements.

		June	July
	Demand (ME)	89	94
ME	Fodder beet	72	72
	Baleage	30	30
	TOTAL	102	102
kg DM	Fodder beet	6	6
	Baleage	3	3
	TOTAL	9	9

Table 4.7 Winter supplements consumed for the proposed composting barn system.

	No. cows wintered	Days	Fodder beet fed (kgDM/hd/d)	Total fodder beet fed (t DM)
Fodder Beet				
June/July	441	61	6.0	161.4
Transition	441	10	3.0 (avg.)	13.2
Early/late calvers	-	-	-	41.4
Sub-total				**216.0**
Baleage				
	No. cows wintered	Days	Baleage fed (kgDM/hd/d)	Total baleage fed (t DM)
June/July	441	61	3.0	80.7
Transition	441	10	3.0 (avg.)	13.2
Early/late calvers	-	-	-	20.7
Sub-total				**114.6**
TOTAL				**330.6**

Post-calving, daily energy requirements will increase as a result of energy demand for milk production (Table 4.5). The diet during lactation will consist primarily of pasture, with maize silage and baleage fed in the composting barn to facilitate ME requirements. Table 4.9 provides details of the lactation diet including animal demand and feed supply. It was assumed that pasture would be the main constituent of the diet with pasture availability based off the seasonal growth curve and feed values stated in Table 4.8 (DairyNZ, 2017b). Maximum pasture was fed keeping pasture covers above 1500 kg DM/ha (Fig. 4.2). Maize silage and baleage was fed at 8 MJ ME/cow/day (2.8 kg DM/cow/day) and 21 MJ ME/cow/day (2.1 kg DM/cow/day), respectively. Total kilograms of dry matter fed averaged out at 17.9 kg DM/cow/day, slightly below the maximum dry matter intake of 4% of live weight (20 kg DM/cow/day).

Table 4.8 Feed value (MJ ME/kg DM) of pasture and supplements. Adapted from DairyNZ (2017b).

Feed Type		ME (MJ ME/kg DM)
Pasture	Spring	12.0
	Summer	10.5
	Autumn	11.5
	Winter	11.0
Maize Silage		10.3
Baleage		10.0
Fodder Beet		12.0

Table 4.9 Lactation diet (MJ ME/cow/day (ME); kg DM/cow/day) based on metabolisable energy requirements for the composting barn system.

		Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
	Demand (ME)	201	208	215	208	201	194	186	179	193	202
ME	Pasture	171	159	166	159	152	145	137	130	144	153
	Maize Silage	28	28	28	28	28	28	28	28	28	28
	Baleage	21	21	21	21	21	21	21	21	21	21
	TOTAL	201	208	215	208	201	194	186	179	193	202
kg DM	Pasture	13.8	13.2	13.8	13.2	12.6	13.8	13.0	11.3	12.5	13.3
	Maize Silage	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
	Baleage	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
	TOTAL	18.7	18.1	18.7	18.1	17.5	18.6	17.9	16.1	17.3	18.1

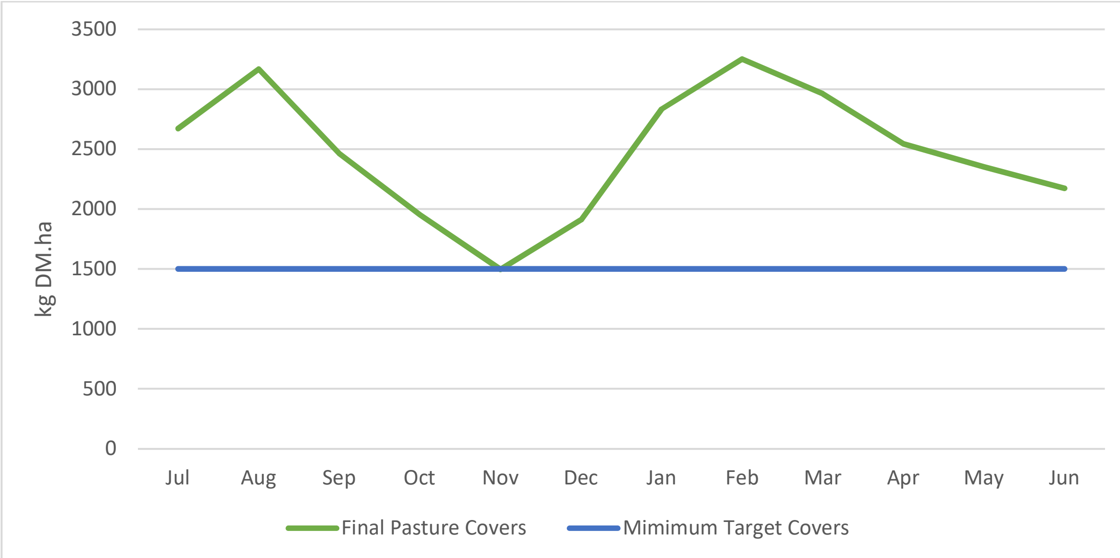

Figure 4.2 Pasture covers for LUDF with composting barn.

Crop Rotation

To meet cow supplementary requirements and assuming fodder beet and maize silage crops both yield 20 t DM/ha, then 12 ha of fodder beet and 24 ha of maize silage is required to be sown. It is proposed that 24 ha of maize silage is sown in October and harvested in March. Half of the 24 ha can then be sown into a permanent ryegrass/clover mix and the remaining 12 ha can be sown into an annual grass before sowing fodder beet in late October. The fodder beet will then be grazed in June and July before being sowing into permanent pasture for a five year rest phase before the rotation begins again (Table 4.10).

In addition, due to surplus pasture supply in spring and summer, 25 ha of grass was cut for baleage in October, November and December. Assuming an average yield of 1.5 t DM/ha, this equated to a total of 112.5 t DM available to be used.

Table 4.10 Cropping rotation for composting barn system. MS = maize silage; FB = fodder beet; R/C = perennial ryegrass/white clover mix.

	Block 1 (24 ha)		Block 2 (24 ha)		Block 3 (24 ha)		Block 4 (24 ha)		Block 5 (24 ha)		Block 6 (24 ha)		Block 7 (24 ha)	
Year 1	MS		R/C		R/C		R/C		R/C		R/C		FB	R/C
Year 2	FB	R/C	MS		R/C		R/C		R/C		R/C		R/C	
Year 3	R/C		FB	R/C	MS		R/C		R/C		R/C		R/C	
Year 4	R/C		R/C		FB	R/C	MS		R/C		R/C		R/C	
Year 5	R/C		R/C		R/C		FB	R/C	MS		R/C		R/C	
Year 6	R/C		R/C		R/C		R/C		FB	R/C	MS		R/C	
Year 7	R/C		R/C		R/C		R/C		R/C		FB	R/C	MS	

Chapter 5
Economic Analysis

5.1 Introduction

The following economic analysis investigates the financial performance of the LUDF with and without a composting barn. The following chapter provides monthly cashflows, an annual budget, and twenty-year investment appraisal (including depreciation and loan schedules) for both the existing LUDF system (2017/18) and the proposed composting barn system as well as the critical financial assumptions used to compile these outputs. All financial figures for the current system were obtained from published records on the LUDF webpage (SIDDC, 2018). It was assumed that the LUDF had no debt to allow for comparisons with the proposed system as well as other farms in New Zealand.

The economic analysis aims not to answer whether a composting barn is financially viable or not, as there are too many assumptions due to the pioneering stage of the system, but rather aims to investigate and identify the critical components that will affect the economic success of a composting barn system.

5.2 Financial Assumptions

5.2.1 Cost Assumptions

Composting barn costs

The composting barn design was based off the Allcock system with minor adjustments, including composting area, made to fit the LUDF system. Design and construction cost projections were received from construction company Calder Stewart (D. Sutton, personal communication, November 13, 2018) and totalled \$765,000 for a 280 cow barn (\$2,732/cow). Total costs of designing and constructing two barns capable of housing 560 cows was therefore assumed at \$1,530,000. In reality, it is quite likely that this figure may be reduced to some extent due to cost and building efficiencies in designing and constructing two barns beside each other. A cost breakdown of the composting barn is provided in Table 5.1. Note this price is for construction in the Canterbury area only and will vary between regions. The barn design may also vary considerably between farms depending on cow numbers and farmer preference. For instance, an exterior concrete yard and concrete feed troughs are not essential items and would result in cost savings of approximately $104,471. The area of concrete surrounding each composting bay will also vary depending on cow numbers with each square metre costing approximately $336.

Excluded in the construction costs were the costs of land preparation and digging of foundation holes, resource and building consent, electrical work and storm water drainage which were assumed at $100,000 for both barns. In addition, the costs of water troughs ($400 per trough; Askin & Askin, 2016), lining for the composting areas ($6.60/m^2 for 500 micron lining; Askin & Askin, 2016), maize bunker ($75,000; A. Syben, personal communication, November 10, 2018) and a utility tractor ($10,000, K. Woodford, personal communication, September 28, 2018) for daily tilling of the bedding were added onto this. Total costs therefore equated to $1,737,298 ($3112.51/cow; Table 5.2).

Depreciation of the barn was assumed at 2.5% as per the diminishing value depreciation rates set by the Inland Revenue Department (IRD, 2013).

Table 5.1 Cost breakdown of a 280 cow composting barn in Canterbury. Retrieved from Calder Stewart (D. Sutton, personal communication, November 13, 2018).

	Total ($)	Per cow ($)
Preliminary and General	83,097	149
Design	18,260	33
Concrete Foundation Pads	28,389	51
Concrete Slabs (Compost area)	194,073	348
Concrete Yard (Exterior)	44,741	80
Structural Steel	224,974	403
Roof Cladding	102,610	184
Feed Troughs	59,730	107
Pipework (above feed troughs only)	9,126	16
TOTAL	**765,000**	**2,732**

Table 5.2 Costs associated with composting barn construction and set-up for 560 cows.

		Composting Barn Costs	
Item	Cost/barn ($)	Total cost ($)	$/cow
Composting barn*	765,000	1,530,000	2,732.00
Compost area lining	10,349	20,698	37.10
Water troughs	800	1,600	2.87
Land prep. and consents	50,000	100,000	179.21
Utility tractor	10,000	10,000	17.92
Maize bunker	75,000	75,000	134.41
Total	**911,149**	**1,737,298**	**3,103.51**

***retrieved from Calder Stewart (D. Sutton, personal communication, November 13, 2018).**

Cost of Barn Bedding

The cost of bedding is also an extra cost to the composting barn system and was valued at $20/m^3$, whether than be Miscanthus or sawdust, with each cow requiring 3 – 5 m^3 per annum (K. Woodford, personal communication, September 25, 2018). The variability in per cow requirements of bedding is a result of variations in the climate between years. For the purposes of this report an average 4 m^3 per cow was used, totalling $44,640 ($80/cow).

Cost of Purchased Capital

It was assumed that the capital required to construct the composting barn and purchase machinery was covered through an interest only bank loan. The interest rate on repayments was assumed at 5.5% per annum based on the current five year bank loans with an additional 1% added to provide a conservative estimate and allow for variation over the 20 year investment period (Interest, 2018; Table 5.3).

Table 5.3 Interest on loan for composting barn system.

	Bank Loan		
	Loan	Interest rate	Annual interest
Composting Barn	1,737,298	6.5%	112,924

DairyNZ Levy

The increased production will result in an increased DairyNZ levy payment. At $0.036/kgMS this accumulates to an extra $2,008.

Supplementary Feed Costs

Due to maize silage and fodder beet now being grown on the milking platform in the proposed composting barn system, and baleage being brought in there will be an associated increase in cropping and supplementary feed costs. It is estimated that the total costs for growing fodder beet is $2,225/ha (Matthew et al., 2011) and the costs for growing and harvesting maize silage is $3,095/ha (Pioneer, 2018). Cost of purchasing baleage (assuming a bale weight of 250 kgDM) including freight was estimated at $70/bale (G. Trafford, personal communication, November 2, 2018) with 1,278 (4.2 bales/day) bales required to supplement pasture. A brief outline of costs is provided in Table 5.4 with a further breakdown of growing and harvest costs supplied in Appendix D.1 (fodder beet) and D.2 (maize silage).

Table 5.4 Supplementary feed costs for the LUDF with a composting barn.

	Area (ha)	c/kgDM	Cost/ha ($)	Total cost ($)
Fodder Beet	24	10.4	2,225	26,700
Maize Silage	12	15.5	3,725	89,400
	No. bales purchased	**c/kgDM**	**Cost/bale ($)**	**Total cost ($)**
Baleage (purchased)	1,278	28.0	70	89,460
			Total Cost ($)	**205,560**

Regrassing Costs

Pasture renewal on the LUDF with a composting system will increase to 22.4% of the milking platform as a result of the new cropping rotation. Each year 24 ha will come out of crop and be sown into a permanent ryegrass/clover mix. In addition, 12 ha of previous maize crop will be sown into a short rotation ryegrass prior to it going into a fodder beet crop in mid-late October.

It is assumed that the 12 ha of permanent and 12 ha of annual grass after maize can be direct drilled at a cost of $100/ha (Askin & Askin, 2014). Following fodder beet, the ground will need to be sprayed out, rolled and drilled at a cost of $137/ha (Askin & Askin, 2014). Sowing rate for both the permanent (Shogun) and short rotation ryegrass (Maverick G2) was assumed at 25 kg/ha (PGG Wrightson Seeds, n.d.). The cost of seed for each was valued at $200/ha and $150/ha (Askin & Askin, 2014), respectively. In addition, the sowing rate and cost for white clover (Kopu II) was assumed at 5 kg/ha (PGG Wrightson Seeds, n.d.) and $75/ha (Askin & Askin, 2014), respectively. Total regrassing costs equated to $12,852 (Table 5.5).

Table 5.5 Regrassing costs in proposed composting barn system.

Seed Costs					
	Seed cost ($/kg)	Sowing rate (kg/ha)	Cost/ha ($)	Total area (ha)	Total cost ($)
Perennial grass (Shogun)	8.00	25	200	24	4,800
Clover (Kopu II)	15.00	5	75	24	1,800
Short rotation ryegrass (Maverick G2)	6.00	25	150	12	1,800
				Total Seed Costs ($)	8,400

Cultivation and Sowing Costs					
	Spraying out ($/ha)	Cultivation costs ($/ha)	Sowing cost ($/ha)	Total area (ha)	Total cost ($)
Permanent pasture (following maize)	17	-	100	12	1,404
Permanent pasture (following fodder beet)	17	20	100	12	1,644
Annual grass (following maize)	17	-	100	12	1,404
				Total Cultivation and Sowing Costs ($)	4,452
				Total Costs ($)	12,852

Fertiliser Costs

Currently, the LUDF applies 178 kg N/ha in split monthly applications from August through to April. Approximately 40 kg S/ha and 65 kg P/ha as superphosphate for maintenance is also applied to the farm. In addition, effluent from the farm dairy is spread over 34 hectares. It is proposed that current fertiliser applications are replicated in the composting barn system, with additional potassium fertiliser applied at a rate of 40 kg K/ha to non-effluent baleage blocks to replace removed nutrients at a cost of $52.80/ha (total cost $3,960). Additional fertiliser will also be required for the maize and fodder beet crops, however the cost of this has been added to the supplementary feed costs.

Furthermore, the annual removal of compost from the composting barn can also be used as a fertiliser product. In order to determine the volume of compost available to be used as fertiliser on the LUDF, adjustments from the Allcock system were used. The Allcock's generate approximately 1500 m^3 of compost per year from the composting barn from 285 cows (T. Allcock, personal communication, October 19, 2018), equating to an average of 5.26 m^3 compost per cow per year.

Using this figure of 5.26 m^3 and an average of 538.5 cows in the composting barns (441 cows wintered in the barn, 558 cows in the barn during lactation), total available compost to be used as fertiliser equates to 2832.5 m^3/year.

It is proposed that the compost generated from the barns is spread evenly over the farm at a rate of 18 m^3/ha. Assuming an estimate of 15 m^3 of compost per tonne (K. Woodford, personal communication, August 3, 2018) this equates to 1.2 t compost/ha. The nutrient content of the compost was based off a sample from the Allcock barn and is provided in Table 5.6 along with the nutrient loading for the LUDF. The carbon to nitrogen ratio of the compost at application, based on the Allcock's compost sample, was 19.3 : 1 which will promote net mineralisation of nitrogen.

Table 5.6 Nutrient content and loading of compost for the LUDF composting barn system.

	Nutrient content (% fresh weight)	Rate applied (kg/ha)	Nutrient loading (kg nutrient/ha)
Nitrogen	0.68	1200	8.2
Phosphorous	0.22	1200	2.6
Potassium	1.19	1200	14.3
Sulphur	0.13	1200	1.6
Calcium	0.53	1200	6.4
Magnesium	0.21	1200	2.6
Sodium	0.08	1200	1.0

Labour Costs

It is assumed that labour costs will increase with all cows now being wintered on farm and lactation length extended. It was assumed that labour costs would increase by 0.5 full time equivalent (FTE) labour units based on a similar study by Journeaux (2013). Assuming 1.0 FTE is worth $50,000, then the increased labour cost was estimated at $25,000.

Tractor Operating Costs

As a result of in-shed feeding during lactation and the dry period there will be an associated cost regarding fuel and tractor maintenance (Table 5.7). The currently owned 100HP tractor and feed-out wagon will be used for feeding out in the barn. Fuel consumption was assumed at 14 litres per hour at a cost of $1.65 per litre (AA, 2018) while repairs and maintenance (R&M) was assumed at $8 per hour (Askin & Askin, 2014).

In addition, daily tilling of the bedding is required using a small utility tractor and was assumed to take one hour per day. Fuel consumption was assumed at 5 litres per hour at the same cost of $1.65 per litre, while R&M was assumed at $2 per hour (Askin & Askin, 2014).

Table 5.7 Tractor operating costs.

		Feeding-out		
	Hours/day	Hours/year	Fuel/year ($)	R&M/year ($)
Year-round	1	365	8,431.50	2,920.00
		Tilling		
	Hours/day	Hours/year	Fuel/year ($)	R&M/year ($)
Year-round	1	365	3,011.25	730.00
TOTAL	-	-	11,442.75	3,650.00

Farm Dairy and Electricity Costs

Farm dairy and electricity costs were assumed to increase due to the extra production and days in milk in the composting barn system. As such both set of expenses items were increased on a per kilogram of milk solids basis from cashflow of the existing LUDF without a composting barn (Table 5.8).

Table 5.8 Farm dairy and electricity costs.

	LUDF (without CB)		**LUDF (with CB)**	
	$/kgMS	Total ($)	$/kgMS	Total ($)
Farm dairy	0.04	9,051	0.04	13,057
Electricity (farm dairy and water supply)	0.11	27,657	0.11	35,907

Repairs and Maintenance Costs

As the composting barns have a much simpler fit-out in comparison to other cow housing facilities, particularly freestalls, the requirement for repairs and maintenance is considerably less (K. Woodford, personal communication, September 25, 2018). A small, yet conservative increase of $2,000 for building repairs and maintenance was therefore added to the proposed system.

Rates and Insurance

Rates and insurance will increase slightly with the addition of the composting barns on the LUDF. Rates were assumed to increase from $12,571 to $13,500 and insurance was assumed to increase from $10,057 to $12,000.

Animal Health and Breeding

It is unclear how the incorporation of composting barns on the LUDF will affect animal health and breeding costs as no studies to date have investigated this in the New Zealand context. Journeaux (2013), however, stated that differences in animal health costs were insignificant between pasture and pasture plus housing systems, although composting barns did not feature in his study. Similarly, in a study by de Wolde (2006) comparing outdoor and indoor systems, animal health costs were deemed to be budget neutral. Therefore, despite overseas literature suggesting that animal health can be improved in composting barn systems (Barberg *et al*., 2007; Lobeck *et al*., 2011) the costs involved were kept the same as the existing situation.

Likewise, while literature suggests that fertility can be improved though improved cow condition in barns (Journeaux, 2013) and thus breeding costs reduced in hybrid systems there is no clear evidence on the magnitude of cost reduction. As such, breeding costs have remained the same in both systems.

5.2.2 Cost Benefit Assumptions

Saved Costs from not Wintering Off

The incorporation of the composting barn means cows can now be wintered on-farm. This is a direct saving of $148,340 based on the 2017/18 season winter cow grazing expense. In addition, the cost of freight (assumed at $10/head each way) for transporting stock to and from the winter grazing block is saved. This is a direct saving of $11,160.

Young Stock Grazing Off

All replacement stock will remain grazed off-farm, however with the incorporation of the composting barn and change in feed system there will be surplus pasture available in winter (Fig. 4.2). As such, replacement stock will be brought back on farm one month earlier in mid-June at a saving of $5,148 ($44/head).

Savings Associated with Reduced Replacement Rate

Currently, the LUDF rears 140 heifer calves keeping 128 as replacement stock. The remainder are sold as rising one-year (R1) heifers. With the addition of a composting barn, a reduction in the replacement rate from 23% (128 heifers) to 21% (117 heifers) provides the farm with two options. Option one would be for the LUDF to continue to rear 140 calves but only keep 117 as replacement stock while option two would be to rear less, assume 130 calves, and still keep 117 as replacement stock. Option one provides greater revenue from sales of surplus rising one-year (R1) heifers but has greater feed and off-farm grazing costs associated with the extra 10 heifers reared. Conversely, option two provides less revenue from sales of R1 stock but also has less feed and off-farm grazing costs. Table 5.9 provides a cost analysis of both options with option two providing a $4,040 cost saving over option one. Cost figures were obtained from the existing LUDF cashflow available online (SIDDC, 2018) and adjusted on a per cow basis, with the exception of the heifer sale price which was assumed at $691/cow from the IRD national average market value scheme (IRD, 2018b).

Table 5.9 Cost analysis of rearing 140 versus 130 replacement stock.

Replacement Numbers			
	Heifers reared	No. heifers required to enter herd	Surplus heifers
Option 1	140	117	23
Option 2	130	117	13
Off-Farm Grazing Cost			
	No. heifers grazed	Grazing cost ($/head)	Total grazing cost ($)
Option 1	140	880	123200
Option 2	130	880	114400
Calf Feed Cost			
	No. heifer calves	Cost/head ($)	Total calf feed cost ($)
Option 1	140	215	30,100
Option 2	130	215	27,950
Heifer Sales			
	No. surplus heifers	Price/head ($)	Heifer sales ($)
Option 1	23	691	15,893
Option 2	13	691	8,983

Financial Outcome				
	Total grazing cost ($)	Total calf feed cost ($)	Total heifer sales ($)	Total Cost ($)
Option 1	123,200	30,100	15,893	137,407
Option 2	114,400	27,950	8,983	133,367

Increased Milk Production

An additional 100 kg MS/cow was assumed in the composting barn system due to an extra 41 days in milk, improved cow condition, better feeding regime, and less energy required for maintenance. At $6.75/kg MS this relates to an increase of $376,650 ($675/cow; $2,353/ha) in milk income received.

Increase in Pasture Production

Pasture production was assumed to increase due to reduced pugging damage. Research has shown that severely pugged pastures in spring produce approximately 40% less dry matter than undamaged pasture in the following season. For each hectare of damaged pasture on the LUDF with a normal production of 21,000 kgDM (DairyNZ, 2016a) this is equivalent to a loss of 8,400 kgDM, at 20 c/kgDM this is a revenue loss of over $1,680 per hectare. However, de Klein (2001) showed that the financial benefit of eliminating pugging damage was out-weighed by the negative effects of increased machinery traffic as a result of conserving feed and making supplements. As there would not be a significant increase in mechanical harvesting of feed in the new system an assumption of a 2% increase in pasture production over the whole farm was assumed based on recommendations by Journeaux (2013).

5.2.3 Investment Appraisal Assumptions

The following investment appraisal assumptions were kept the same for both the existing LUDF system and proposed composting barn system to ensure a fair comparison (Table 5.10).

Tax Rate

The Inland Revenue Department (IRD) tax rate of 28% on company's profits was used (IRD, 2018a).

Capital Gain Rate

The capital gain rate was assumed at 4.0% per annum.

Inflation

The inflation rate was assumed at 2% as this is the mid-range point set by the Reserve Bank of New Zealand (RBNZ, 2018).

Income Development

The income development rate was used to estimate the annual increase in income and was assumed at 1.5% per annum.

Table 5.10 Investment appraisal assumptions.

Tax Rate	28%
Capital Gain	4%
Inflation	2%
Income Development	1.5%

Fonterra Dairy Payout and Dividend Price

The dairy payout was assumed to remain the same as the existing LUDF system at $6.75/kg MS to provide a fair comparison. Similarly, the dividend payout was removed in both systems as was the value of Fonterra shares in the existing situation and the cost of purchasing additional Fonterra shares in the proposed composting barn system. This was to enable fair comparisons with other non-Fonterra supplying farms.

5.3 Results

5.3.1 Physical Summary

Table 5.11 provides a physical comparison summary of the LUDF with and without a composting barn. Peak cow numbers and stocking rate have remained the same, however kilograms of live weight (Lwt) per cow and per hectare have increased by 4.2%.

Full time equivalent (FTE) labour has increased by 0.5 units with the addition of the composting barns, while cows per FTE and kilograms of milksolids per FTE declined by 11.9% and 3.6%, respectively. Total milksolids increased by 100 kg MS per cow resulting in a 20.7% and 13.7% increase in milksolids per hectare and per kilogram of live weight, respectively.

Total feed eaten has increased under the composting barn system by 0.9 t DM/ha. This is a result of a 3.5 t DM/ha increase in pasture and crop eaten, 0.7 t DM/ha increase in imported supplement and the removal of 3.3 t DM/ha of feed grazed off farm during winter.

Table 5.11 Physical summary of the LUDF with and without a composting barn (CB).

	LUDF (without CB)	LUDF (with CB)
Peak cow numbers	558	558
Cows/ha	3.5	3.5
Kg Lwt/cow	480	500
Kg Lwt/ha	1673	1743
Replacement %	23%	21%
FTE paid labour	3.7	4.2
Cows/FTE	151	133
kgMS/FTE	73,143	77,721
kgMS/cow	485	585
kgMS/ha	1690	2039
kgMS/kg Lwt	1.01	1.17
DIM	264	305
Pasture and crop eaten (t DM/ha)	13.9	17.4
Supplement imported (t DM/ha)	1.3	2.0
Grazing off (t DM eaten/ha)	3.3	0
Total feed eaten (t DM/ha)	18.5	19.4
Main supplement type	Silage	Maize silage, baleage, fodder beet

5.3.2 Financial Analysis

Annual Budget

Table 5.12 provides a brief overview of the major income and expense items for the LUDF with and without a composting barn. A full annual budget can be found in Appendix E.

Total income has increased with the incorporation of the composting barn compared to the existing system by 19.2% from $1,910,037 to $2,276,921. This is due largely to the 100 kg MS increase with the composting barn that allowed for an additional $376,650 of milk income. Stock income decreased slightly due to fewer cull calves.

Total farm working expenses (FWE) decreased slightly by 1.6% from $875,997 ($3.24/kg MS) without the composting barn to $862,390 ($2.64/kg MS) with the incorporation of the composting barn system. The largest five FWE in the existing situation without the composting barn were wages, winter cow grazing, young stock grazing, supplementary feed (includes feed purchased and grown on farm) and fertiliser which accounted for 79.8% of total FWE and 38.6% of total income. The same items (besides winter grazing) also contributed the most to the FWE for the composting barn system accounting for 77.0% of total FWE and 29.3% of total income (Fig. 5.1). The largest difference between the systems was a $109,533 (121%) increase in supplementary feed costs in the composting barn system, however this was somewhat offset by the removal of winter cow grazing in the new system which resulted in a direct cost saving of $148,340. Whilst total expenditure in other areas including wages and fertiliser may have increased, the extra cost was in most cases absorbed by the increase in milksolids which resulted in expense items being lower on per kilogram of milksolids basis. For instance, while wages increased by $25,000 with the incorporation of the composting barn the total cost per kilogram of milksolids decreased by $0.08.

Table 5.12 Condensed annual budget comparison for the LUDF with and without a composting barn (CB) including all income items and largest expense items. *MS = milksolids.

	LUDF (without CB)		LUDF (with CB)	
	Total	$/kgMS	Total	$/kgMS
Income				
Milk Income (MS x $6.75)	1,826,753	6.75	2,276,403	6.75
DairyNZ Levy (MS x $0.036)	-9,743	-0.04	-11,751	-0.04
Stock Income (sales – purchases)	93,027	0.37	85,270	0.28
Total Income	**1,910,037**	**7.06**	**2,276,921**	**6.98**
Expenses				
Wages	248,910	0.92	273,910	0.84
Winter grazing	148,340	0.55	0	0.00
Young stock grazing	123,198	0.46	109,252	0.33
Supplementary feed	93,027	0.34	205,560	0.63
Fertiliser (incl. nitrogen)	72,159	0.27	79,155	0.23
Total Farm Working Expenses	**875,997**	**3.24**	**862,390**	**2.64**

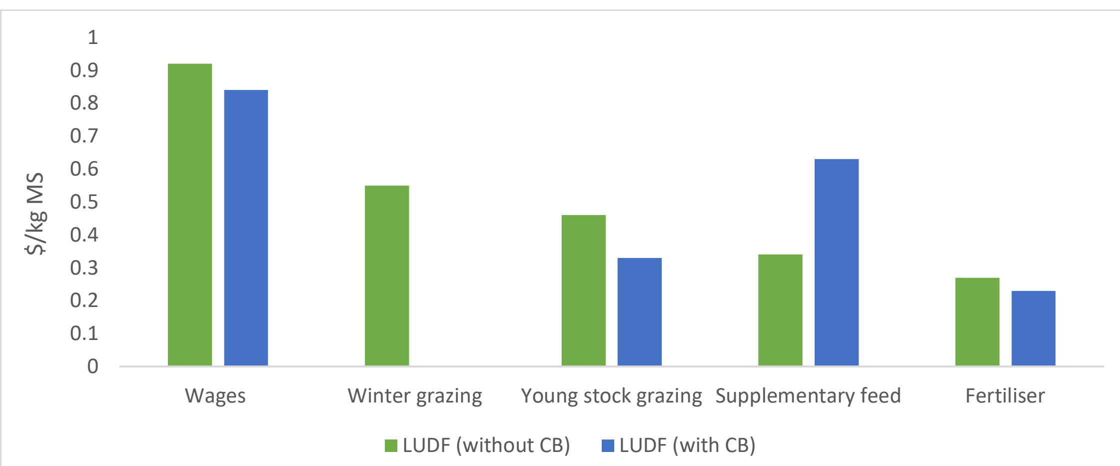

Figure 5.1 Major expenditure items for the LUDF with and without a composting barn.

Accounts Analysis

Table 5.13 summarises the accounts for the LUDF with and without a composting barn with an explanation of each of the terms provided in Table 5.14. Earnings before interest and tax (EBIT) is 39.9% higher with the incorporation of the composting barn on the LUDF compared to without the barn. Operating expenses have also increased (+19.5%) but to a lesser extent than EBIT. As such, total dairy operating profit is 18.5% (+$102,346) greater with the incorporation of the composting barn on the LUDF. However, on a per kilogram of milksolids basis, dairy operating profit has remained fairly similar between the systems at $2.01/kg MS and $2.04/kg MS with and without the composting barn, respectively.

Table 5.13 Summary of accounts analysis for LUDF with and without a composting barn.

	LUDF (without CB)		LUDF (with CB)	
	Total ($)	$/kg MS	Total ($)	$/kg MS
Net cash income	1,910,037	7.06	2,276,921	6.98
Farm working expenses	875,997	3.24	862,390	2.64
Depreciation	218,019	0.81	272,771	0.84
EBIT	816,021	3.02	1,141,760	3.50
Interest	0	0.00	112,924	0.35
Income tax	263,800	0.97	374,269	1.15
Operating expenses	1,357,816	5.02	1,622,354	4.97
Dairy operating profit	552,221	2.04	654,567	2.01

Table 5.14 Definitions to accompany accounts analysis.

Definitions	
Net cash income (NCI)	Sum of all cash income items
Farm working expenses (FWE)	Expenses attributable to on-farm production
EBIT	Sum of all cash operations before interest and tax
Interest	Annual interest payments on loan
Depreciation	Estimate of the lost value of depreciating assets
Operating expenses	Sum of farm working expenses, depreciation, interest and tax
Dairy operating profit (DOP)	Net cash income minus total operating expenses (annual surplus/deficit)

5.3.4 Assets and Liabilities

Total assets increased by $1,737,298 in the composting barn system due to the addition of the housing facility on the LUDF. Total liabilities also increased by the same amount in the composting barn system due to the bank loan required to pay for construction of the barn and associated infrastructure and equipment. Total equity therefore remained the same at $10,601,127.72 but equity percent dropped from 100% without the composting barn to 85.9% with the composting barn on the LUDF (Table 5.15).

Table 5.15 Statement of assets and liabilities for the LUDF with and without a composting barn.

	LUDF (without composting barn)	LUDF (with composting barn)
ASSETS		
Land and developments	8,203,681.90	8,203,681.90
Plant	738,646.12	738,646.12
Buildings	389,000.00	2,116,298.00
Irrigation	646,094.40	646,094.40
Machinery	218,543.34	218,543.34
Vehicles	179,039.46	189,039.46
Effluent	130,260.05	130,260.05
Water infrastructure	95,862.45	95,862.45
TOTAL ASSETS	**10,601,127.72**	**12,338,425.72**
LIABILITIES		
Bank loan	0	1,737,298
TOTAL LIABILITIES	**0**	**1,737,298**
EQUITY	**10,601,127.72**	**10,601,127.72**

5.3.5 Key Performance Indicators

Farm working expenses as a proportion of kilograms of milksolids and net cash income decreased by 18.5% and 8.0%, respectively, with the addition of the composting barn on the LUDF. Debt servicing (DS) increased by 5% compared to the existing system, which assumed no debt, as a result of the loan required to pay for construction of the composting barn. The return on asset (ROA) and return on equity (ROE) was the same for the LUDF without a composting barn as no debt was assumed. This put the LUDF into a 100% equity situation. In comparison, with the incorporation of the composting barn ROA and ROE increased to 9.3% and 9.7%, respectively (Table 5.16).

Table 5.16 Key performance indicators (KPIs) for the LUDF with and without a composting barn.

	LUDF (without CB)	LUDF (with CB)
FWE/kgMS	$3.24	$2.64
FWE/NCI	45.9%	37.9%
DS/NCI	0%	5.0%
EBIT/kgMS	$3.02	$3.50
ROA	7.7%	9.3%
ROE	7.7%	9.7%
Equity %	100%	85.9%

5.3.6 Investment Appraisal

Internal rate of return (IRR) and net present value (NPV) were used to analyse the profitability of incorporating composting barns onto the LUDF. Full investment appraisals to determine the IRR and NPV are provided in appendix E. The nominal post finance and tax IRR for the existing LUDF system without a composting barn was 8.27% and decreased to 6.14% when accounting for inflation. Thus, at a discount rate of 6.14% the NPV was equal to zero, with all discount rates below this showing profitable returns. Nominal and real EBIT IRR increased to 10.62% and 8.45%, respectively (Table 5.17). In contrast, the nominal and real post finance and tax IRR increased under the composting barn system by approximately two percentage points to 10.37% and 8.21%, respectively. Similarly, the EBIT IRR increased to 13.85% and 11.62% (Table 5.18).

The post finance and tax marginal return, that is the return on invested capital, on the LUDF with a composting barn was relatively high at 30.32% and 27.61%, respectively (Table 5.19).

Table 5.17 Internal rate of return (IRR) and net present value (NPV) for LUDF without a composting barn.

LUDF (without a composting barn)			
		Nominal	Real
IRR (post finance and tax)		8.27%	6.14%
IRR (EBIT)		10.62%	8.45%
	Discount Rate		
NPV (post finance and tax)	2.0%	14,730,377	8,094,757
	4.0%	8,202,910	3,469,235
	6.1%	3,350,639	0
	8.0%	358,560	-2,160,394
	10.0%	-2,001,579	-3,882,371

Table 5.18 Internal rate of return (IRR) and net present value (NPV) for LUDF with a composting barn.

LUDF (with a composting barn)			
		Nominal	**Real**
IRR (post finance and tax)		10.37%	8.21%
IRR (EBIT)		13.85%	11.62%
	Discount Rate		
NPV (post finance and tax)	2.0%	19,348,732	11,938,376
	4.0%	12,059,869	6,712,685
	6.0%	6,886,033	2,967,484
	8.3%	2,832,062	0
	10.0%	423,751	-1,783,669

Table 5.19 Marginal internal rate of return and net present value for the LUDF with a composting barn.

Marginal Return			
		Nominal	**Real**
IRR (post finance and tax)		30.32%	27.61%
	Discount Rate		
NPV	15.0%	1,347,448	1,035,857
	20.0%	772,340	535,212
	27.6%	163,327	0
	30.0%	18,025	-128,647
	35.0%	-235,121	-353,835

Chapter 6
Environmental Analysis

6.1 Introduction

The following chapter provides an analysis of the environmental performance of the LUDF with and without a composting barn. Overseer® Nutrient Budgets version 6.3.0 has been used to generate both farm models with the existing LUDF Overseer® data obtained from LUDF management (R. Pellow, personal communication, June 18, 2018).

While Overseer® is currently accepted as the best available tool to estimate nutrient leaching losses and greenhouse gas emissions from a farm, it must be recognised that Overseer® is a relatively new and complex tool as are the use of barns in the New Zealand context. Therefore, the results presented in the following sections are constrained by Overseer® version 6.3.0 and the information within Overseer®. As such, the importance of the results is in the direction and magnitude of change in nutrient losses and greenhouse gas emissions between the LUDF with and without a composting barn rather than the absolute values.

6.2 Changes to Existing Model

To construct the proposed composting barn system the existing LUDF Overseer® data was replicated with adjustments made where necessary. A number of assumptions had to be made to enable these adjustments, particularly surrounding the composting barn set-up. These assumptions are detailed below.

6.2.1 Composting Barn

Modelling of the composting barn within Overseer® was difficult as it is a very new concept that is not recognised by the software. Assistance was therefore sought to ensure that the barn was modelled as accurately as possible to reflect the composting barn system (J. van Dijk, personal communication, October 18, 2018; Table 6.1).

The barn was set-up as a covered housing facility with a carbon rich lined bunker. The bunker refers to a concrete pit in which effluent accumulates and which can be lined to contain the effluent (Overseer, 2018). In reality, effluent in a composting barn accumulates in the composting area within the barn, rather than a bunker below, of which there is no option to select from Overseer®, unless the barn is set-up as an uncovered facility such as stand-off pad. However, it was deemed that setting up as a covered facility would provide a more accurate representation of the structure.

In a composting barn the majority of effluent is composted *in situ* with the bedding material while cows are resting on the composting area. Overseer® is not capable of dealing with effluent in this way and as such the barn was modelled so that all solid and liquid effluent that was captured in the bunker below the housing facility was cleaned out monthly and exported off farm. The compost was then brought back on-farm as a compost fertiliser product to model compost being removed from the barn and stored on concrete until such time it is spread onto pasture. In addition to effluent excreted while resting, a smaller amount of effluent is also excreted while cows are eating from designated feed troughs and deposited onto a concrete feeding apron which is regularly scraped into the farm's effluent management system. To achieve this within Overseer®, a concrete feeding apron was selected as present and scraped without the use of water into an effluent management system. It was estimated that the average time spent on the concrete feed apron by cows was four hours per day.

Management of the composting barn was set up as a hybrid system (indoor plus outdoor grazing) with all cows using the barn. Daily outdoor grazing times were set at 12 hours from October through to March, and four hours during the high leaching risk period of May through to August. For the shoulder months of April and September, grazing time was slightly increased to six hours. The remaining time was either spent in the barn, in the cowshed or walking. The breakdown of these times in Overseer® is unknown.

Table 6.1 Composting barn set-up parameters in Overseer®.

General	
Pad type	Covered wintering pad or animal shelter
Bunker management	Carbon rich (sawdust, bark, woodchips) lining material, 12 months between first adding animals and cleaning out of bunker
Solids management	Exported No storage before solids are spread
Liquid effluent	All exported
Management	
Feeding regime	Wintering pad plus grazing Grazed out most of the farm before moving animals onto pad
Time spent on concrete feeding apron	4 hours per day when feeding apron is in use
Percentage of milking cows on pad	100% when housing in use
Hours per day grazing	Oct-Mar 12 hrs; Apr 6hrs; May-Aug 4 hrs; Sept 6 hrs

6.2.2 Cropping Blocks

In addition to the existing blocks in the base LUDF model, two cropping blocks (fodder beet and maize silage) were added into the system (Table 6.2). These blocks were set up so that the crops would rotate through the North Block and parts of the South Block where soil profile, particularly drainage, would have the least impact on crop growth. As Overseer® demands that the cropping area must be less than or equal to 25% of the pastoral blocks that the crop rotates through, two blocks (K-Line block – gley soil; South block sprinklers – gley soil) with poor drainage had to be utilised. In reality, it would be possible to not crop on these soils by reducing the pasture rest phase for a couple of paddocks from five to four years in order to avoid cropping the gley soils. This would still provide sufficient time to rebuild soil fertility and structure.

Table 6.2 Block type and area (ha) for the LUDF in Overseer®.

Block Name	Type	Effective area (ha)
Effluent block (Temp_1a.1)	Pastoral	18.1
Effluent block (Barr_5a.1)	Pastoral	6.8
Effluent block (Waka_3a.1)	Pastoral	8.8
K-line block (Flax_4a.1)	Pastoral	9.9
North block sprinklers (Waka_1a.1)	Pastoral	6.9
North block sprinklers (Temp_4a.1)	Pastoral	4.6
North block sprinklers (Temp_2a.1)	Pastoral	5.5
North block sprinklers (Waka_3a.1)	Pastoral	4.4
North pivot - non eff (Barr_5a.1)	Pastoral	3.3
North pivot - non eff (Temp_4a.1)	Pastoral	2.6
North pivot - non eff (Waka_3a.1)	Pastoral	5.1
North pivot - non eff (Temp_2a.1)	Pastoral	3.1
North pivot - non eff (Temp_1a.1)	Pastoral	11.0
South pivot (Waka_1a.1)	Pastoral	20.9
South pivot (Waka_3a.1)	Pastoral	8.9
South pivot (Flax_4a.1)**	Pastoral	19.2
South block sprinklers (Flax_4a.1)	Pastoral	4.8
South block sprinklers (Waka_1a.1)	Pastoral	6.6
South block sprinklers (Waka_3a.1)	Pastoral	11.0
Plantings**	Trees and scrub	1.3
Dairy**	House	3.1
Pasture – Maize*	Fodder crop	-
Maize – Fodder Beet*	Fodder crop	-

***blocks included in composting barn system only**
****blocks not included in cropping rotation in composting barn system**

The maize crop was set up to have a rotation area of 24 ha. The crop was sown in October and harvested in March with pasture resown in April. Irrigation was provided throughout the growing season. Fertiliser applications of 200 kg/ha of potassium chloride (0-0-100-0), 250 kg/ha of incorporated Cropmaster DAP (44-50-0-2) and 150kg/ha of urea was applied in split application in October and December (Fig. 6.1).

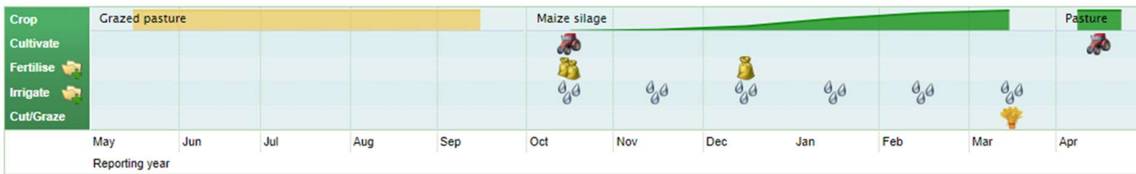

Figure 6.1 Maize crop set-up in Overseer®.

The fodder beet crop was set-up to have a rotation area of 12 ha. The crop was sown in October and grazed *in situ* in June and July. Pasture was resown in September, leaving one month for the soil to dry out and cultivation work to occur. Fertiliser was applied in October as per the work of Matthew *et al*. (2011) with 100 kg/ha of potassium chloride (0-0-50-0), 50 kg/ha of magnesium oxide (0-0-0-0), and 150 kg/ha of Cropmaster Boron plus (25-28-0-1). In addition, 100 kg/ha of salt and 1600 kg/ha of lime was also applied prior to sowing. In accordance with recent work by Chakwizira *et al*. (2016) surrounding N requirements of irrigated fodder beet crops grown on shallow soils, 50 kg N/ha was applied in split applications of 10 kg N/ha, 20 kg N/ha and 20 kg N/ha 30, 60 and 90 days after sowing, respectively (Fig. 6.2).

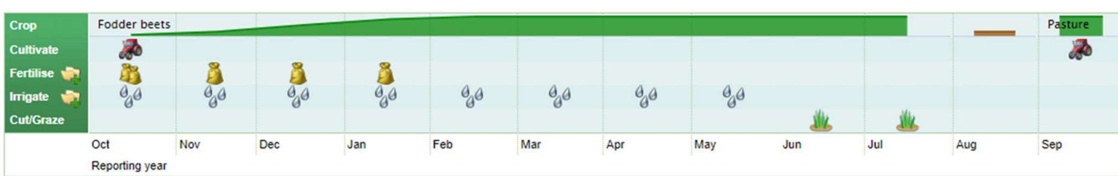

Figure 6.2 Fodder beet set-up in Overseer®.

6.2.3 Supplements Made

An extra 55 t DM of baleage was made with the incorporation of the composting barn on the LUDF due to an increase in pasture surplus compared to the existing system. To achieve this the area baleage was made from increased from 50 ha to 75 ha (Table 6.3). All baleage was fed out in the composting barn during the June and July dry period.

In the existing system, baleage was only made on effluent blocks which supplied sufficient nutrient to account for the removal of nutrients in the baleage. With additional non-effluent blocks being used for baleage, fertiliser inputs of 40 kg K/ha was applied.

Table 6.3 Baleage area (ha) and yield (t DM/ha; t DM) from the LUDF with and without a composting barn (CB).

		LUDF (without CB)		LUDF (with CB)	
Block name	Block area (ha)	t DM/ha	t DM	t DM/ha	t DM
Effluent block (Temp_1a.1)	18.1	1.7	31	1.5	27
Effluent block (Barr_5a.1)	6.8	1.8	12	1.5	10
Effluent block (Waka_3a.1)	8.8	1.8	16	1.5	13
North pivot - non eff (Barr_5a.1)	3.3			1.5	5
North pivot - non eff (Temp_4a.1)	2.6			1.5	4
North pivot - non eff (Waka_3a.1)	5.1			1.5	8
North pivot - non eff (Temp_2a.1)	3.1			1.5	5
North pivot - non eff (Temp_1a.1)	11			1.5	17
North block sprinklers (Waka_1a.1)	6.9			1.5	10
North block sprinklers (Temp_4a.1)	4.6			1.5	7
North block sprinklers (Temp_2a.1)	5.5			1.5	8
TOTAL	-	-	**59**	-	**114**

6.2.4 Supplements Imported

To supplement pasture and maize silage in the composting barn system 320 t DM was brought in as baleage which was double the 160 t DM purchased in the existing LUDF system. All baleage was fed in the composting barn.

6.2.5 Fertiliser

All fertiliser applications in the existing LUDF system were replicated in the composting barn system. This comprised of 178 kg N/ha/yr applied in split applications from August through to April, as well as 250 kg superphosphate per hectare applied in September and October. In addition to these inputs, 40 kg K/ha was added to non-effluent baleage blocks in the composting barn system. Compost from the barns was also spread evenly over the pastoral blocks in October at a rate of one tonne per hectare (37% dry weight). This was slightly less than the assumed rate of 1.2 t/ha stated in Section 5.2.1 as Overseer® could only deal in whole numbers. Table 6.4 provides details of the nutrient content of compost and the rate of nutrients applied.

Table 6.4 Nutrient content of compost (% DM) and rate of nutrient applied (kg nutrient/ha) to pastoral blocks at one tonne compost per hectare.

	Nutrient (%)	Nutrient loading (kg nutrient/ha)
Nitrogen	0.68	6.7
Phosphorus	0.22	2.2
Potassium	1.19	11.9
Sulphur	0.13	1.3
Calcium	0.53	5.3
Magnesium	0.21	2.1
Sodium	0.08	0.8
Carbon	13.1	131

6.3 Overseer® Results

6.3.1 Nutrient Budget Results

Farm System

Nutrient budgets are the key output table of Overseer® and detail the nutrients added and removed from a farm system and include changes in farm pools. Tables 6.5 and 6.6 provide the nutrient budgets for the existing LUDF farm system and the LUDF with the incorporation of a composting barn, respectively. The ‘N to water’ is the key value that determines the farms nitrate leaching in kilograms of nitrogen per hectare per year. The incorporation of the composting barn reduced nitrogen leaching by 32% from 47 kg N/ha/yr to 32 kg N/ha/yr.

The change in nutrient farm pools varied considerably between the two systems. Without a composting barn the LUDF had a net gain of 113 kg N/ha/yr whereas with the incorporation of the composting barn, the LUDF had a net loss of 323 kg N/ha/yr. Large net losses in the inorganic soil pool of 44 kg P/ha/yr and 237 kg K/ha/yr also occurred in the composting barn system compared to net gains of 11 kg P/ha/yr and 37 kg/K/ha/yr without the composting barn.

Table 6.5 Overseer® nutrient budget (kg/ha/yr) for the existing LUDF system without a composting barn.

	N	P	K	S	Ca	Mg	Na
Nutrients added							
Fertiliser, lime & other	163	43	7	52	95	0	0
Fertiliser	163	43	7	52	95	0	0
Rain/clover N fixation	173	0	2	4	2	4	16
Rainfall	2	0	2	4	2	4	16
Biological fixation	171	0	0	0	0	0	0
Irrigation	12	0	8	12	44	10	45
Supplements	26	2	22	2	4	2	1
Supplements imported	26	2	22	2	4	2	1
Nutrients removed							
As products	109	18	26	6	23	2	8
Exported effluent	0	0	0	0	0	0	0
As supplements and crop residues	0	0	0	0	0	0	0
To atmosphere	105	0	0	0	0	0	0
Volatilisation - fertiliser	7	0	0	0	0	0	0
Volatilisation - other	4	0	0	0	0	0	0
Denitrification - background	1	0	0	0	0	0	0
Volatilisation from urine	76	0	0	0	0	0	0
Denitrification from urine	17	0	0	0	0	0	0
To water	**47**	**1.1**	**11**	**68**	**58**	**3**	**9**
Leaching - urine patches	42	0	7	0	33	0	0
Leaching - other	5	0.6	4	68	26	3	9
Runoff	0	0.5	0	0	0	0	0
Change in farm pools							
Plant material	0	0	0	0	0	0	0
Organic pool	113	14	1	-4	0	0	0
Inorganic mineral	0	1	-37	0	-1	-2	-2
Inorganic soil pool	0	11	37	0	64	12	47

Table 6.6 Overseer® nutrient budget (kg/ha/yr) for the LUDF with a composting barn.

	N	P	K	S	Ca	Mg	Na
Nutrients added							
Fertiliser, lime & other	151	43	25	42	113	2	3
Fertiliser	151	42	24	42	76	1	3
Lime	0	0	0	0	37	0	0
Organic	1	0	1	0	0	0	0
Rain/clover N fixation	193	0	2	4	2	4	16
Rainfall	2	0	2	4	2	4	16
Biological fixation	191	0	0	0	0	0	0
Irrigation	15	1	9	15	54	13	55
Supplements	29	5	36	4	9	3	3
Supplements imported	29	5	36	4	9	3	3
Nutrients removed							
As products	140	24	32	8	32	3	9
Exported effluent	366	59	344	33	96	31	26
As supplements and crop residues	0	0	0	0	0	0	0
To atmosphere	174	0	0	0	0	0	0
Volatilisation - fertiliser	7	0	0	0	0	0	0
Volatilisation - other	102	0	0	0	0	0	0
Denitrification - background	55	0	0	0	0	0	0
Volatilisation from urine	8	0	0	0	0	0	0
Denitrification from urine	2	0	0	0	0	0	0
To water	**32**	**1.6**	**6**	**34**	**46**	**5**	**17**
Leaching - urine patches	3	0	1	0	2	0	0
Leaching - other	29	0.6	5	34	44	5	17
Runoff	0	1	0	0	0	0	0
Change in farm pools							
Plant material	-21	-1	-30	0	-2	-2	0
Organic pool	-323	8	2	-10	0	0	0
Inorganic mineral	0	1	-46	0	11	-2	-2
Inorganic soil pool	20	-44	-237	0	-7	-15	27

Block Level

Nitrogen leaching losses from pastoral blocks were greatest on those that applied sprinkler irrigation (90 kg N/ha/yr) compared to those that applied pivot irrigation (30 kg N/ha/yr; including the effluent block), although the magnitude of loss was far more significant on the LUDF without a composting barn compared to the LUDF with a composting barn (Fig. 6.3). The introduction of maize silage and fodder beet increased leaching losses from the composting barn system considerably, contributing 96 kg N/ha/yr and 150 kg N/ha/yr, respectively, to the farms total nitrogen leaching losses.

The change in farm nutrient pools at the block level changed considerably between systems (Table 6.7). With the incorporation of the composting barn on the LUDF soil nitrogen in the organic soil pool showed net losses compared to net gains without the composting barn. Losses from the pastoral blocks (effluent, sprinkler and pivot blocks) on the composting barn were similar at an average of -324 kg N/ha/yr. Nitrogen losses from the maize silage block were similar to the pastoral block, while nitrogen losses from the fodder beet block were considerably higher at -495 kg N/ha/yr. In contrast, nitrogen in the inorganic soil pool increased under the cropping blocks to 91 kg N/ha/yr and 120 kg N/ha/yr for maize silage and fodder beet, respectively.

Phosphorous and potassium in the inorganic pool showed significant losses averaging 51 kg P/ha/yr and 310 kg K/ha/yr from pastoral blocks under the composting barn system compared to the LUDF without a composting barn which showed gains in P and K from the inorganic pool. The maize silage block contributed less to the decrease in the phosphorous inorganic pool (-10 kg P/ha/yr) and provided increases to the potassium inorganic pool of 82 kg P/ha. In contrast, fodder beet contributed -2 kg P/ha/yr and -40 kg K/ha/yr to the inorganic pool.

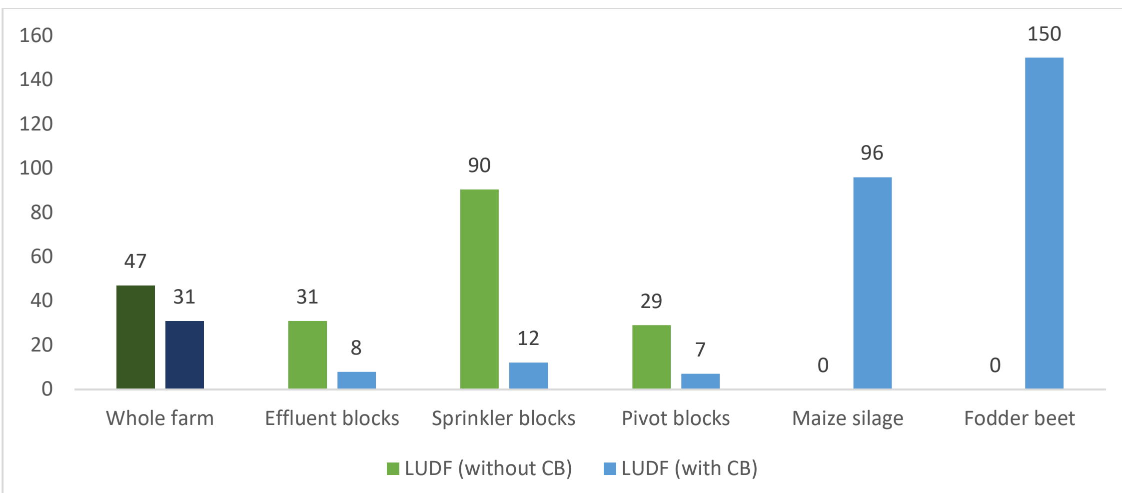

Figure 6.3 Nitrogen (N) leaching losses (kg N/ha/yr) from individual farm blocks and whole farm on the LUDF with and without a composting barn (CB).

Table 6.7 Change in farm organic and inorganic soil pools (kg nutrient/ha/yr) on the LUDF with and without a composting barn (CB).

	LUDF (without CB)						LUDF (with CB)					
	Organic Pool			Inorganic Pool			Organic Pool			Inorganic Pool		
	N	P	K	N	P	K	N	P	K	N	P	K
Effluent blocks	156	14	0	0	26	107	-230	16	0	0	-32	-173
Sprinkler blocks	46	13	0	0	8	-1	-379	15	0	0	-62	-384
Pivot blocks	101	14	0	0	8	8	-363	16	0	0	-60	-373
Maize Silage	0	0	0	0	0	0	-376	-24	0	91	-10	82
Fodder Beet	0	0	0	0	0	0	-495	-26	0	120	-2	-40
Whole Farm	**113**	**14**	**1**	**0**	**11**	**37**	**-323**	**8**	**2**	**20**	**-44**	**-237**

6.3.2 Greenhouse Gas Emissions

Table 6.8 provides estimates of the GHG emissions in CO_2 equivalents (kg/ha/yr) for the LUDF with and without a composting barn system. Methane (CH_4) and nitrous oxide (N_2O) emissions appear to increase with the incorporation of the composting barn from 9,997 kg/ha/yr and 3,302 kg/ha/yr to 11,424 kg/ha/yr and 20,920 kg/ha/yr, respectively. The major increase in N_2O emissions (534%) and methane (14.3%) in the composting barn system has come from enteric emissions and captured effluent, respectively. The accuracy of the composting barn GHG results are questionable and will be discussed in further detail in Chapter 7.

Table 6.8 Overseer® greenhouse gas emission budget for the LUDF with and without a composting barn (CB).

	CO_2 Equivalents (kg/ha/yr)	
	LUDF (without CB)	LUDF (with CB)
Methane	**9997**	**11,424**
Enteric	9865	11,363
Dung	107	34
Effluent	25	27
N_2O emissions	**3302**	**20,920**
Excreta paddocks	2300	219
Excreta effluent	1	19,829
N fertiliser	438	405
Crops	0	10
InDirect	562	457

Chapter 7

Discussion

7.1 Introduction

The purpose of this research project was to identify the critical components that affect the economic and environmental performance of composting barns using the existing LUDF model without a composting barn as a comparison. The literature review in Chapter 2 identified a severe lack of knowledge of composting barn systems in New Zealand, particularly in relation to the changes in a farms nutrient leaching profile and economic profitability when the composting barn is used in a hybrid (indoor-outdoor) system. This led to the following research questions which will be discussed in this chapter.

1. What are the reasons for building composting barns in New Zealand?
2. How will a composting barn affect the production levels of a dairy farm?
3. What are the critical components of the composting barn system that will affect the economic success of a dairy farm?
4. What are the critical components of the composting barn system that will affect the nutrient leaching profile and greenhouse gas emissions on a dairy farm?
5. What are the key constraints to adoption of composting barns in New Zealand and can these constraints be overcome?

7.2 Reasons for Building a Composting Barn

In New Zealand, the decision to invest in off-paddock infrastructure is typically due to a range of reasons including farm management preference, improved utilisation of supplementary feed, decrease in pugging, greater control of pasture, improved working conditions, reduction in off-farm grazing costs and greater profitability (Journeaux & Newman, 2015). The decision to invest then in composting barns rather than other off-paddock infrastructure (including short-term stand-off pads) is likely to be similar to that found in overseas literature and includes improved animal comfort and welfare, improved cleanliness, less concern with cow size (compared to freestalls), and in particular low investment costs (Barberg *et al*., 2007; Eckelcamp *et al*., 2014; Woodford *et al*., 2018).

The cost of constructing a composting barn in this study totalled $3,114 per cow including all the ancillary equipment, land preparation and consents required. This figure was similar to the $1,500 - $,3000 per cow reported by Woodford *et al*. (2018) depending on the individual farm situation and system operated, and much lower than the average cost of freestalls reported at $4,510/cow by Journeaux and Newman (2015) from six case study farms. Compared to stand-off pads or hard-floor shelters designed for short duration weather events, the costs of composting barns are likely to be much higher (Woodford *et al*., 2018). There are also other opportunities with composting barns that may influence the decision to invest in a composting barn and these are detailed below.

Environmental Performance

Preliminary work conducted in this research project suggests that composting barns have significant environmental benefits particularly around nitrogen leaching and is derived from the ability to be able to operate duration-controlled grazing systems. Further discussion around this topic is provided in Section 7.5.

Calving Tool

Calving can be a challenging time on many dairy farms with the often wet and cold conditions making calving difficult, and at times increasing calf mortality rates. Composting barns provide an alternative to calving in the paddock as a calving area can easily be set-up in the barn with a temporary fence providing a warm and controlled environment for cows to calve in. This provides benefits over other housing structures, such as freestalls, which would require additional capital expenditure to incorporate a calving area into. In addition, composting barns also provide greater ability to milk late-calving cows for longer than a traditional pasture-based system due to cows being housed closer to the dairy.

Winter Milking

Composting barns and the incorporation of supplementary feed into the system provide greater opportunity to alter the system from a typical seasonal milking operation to a winter milking operation. This provides opportunities to take advantage of winter premiums and milk empty cows through the dry period and spring to calve in autumn. It is likely that this system would improve the capital efficiency of the investment, returning greater profits to the company. Further studies are needed to quantify the benefits of using composting barns in a winter milking system.

7.3 Effect of Incorporating Composting Barns on Farm Production Levels

This research project assumed an increase of 100 kg MS/cow from 485 kg MS/cow without a composting barn to 585 kg MS/cow with the incorporation of a composting barn on farm and was a result of lowered maintenance requirements, increased supplementary feeding, extended lactation and heavier, better conditioned cows. However, the change in production levels is likely to vary between farms and is largely dependent on the current milksolids production and level of supplementary feed fed in the barn.

It is quite possible to match the composting barn design to the desired system operated. For instance, if a farmer desires to remain operating a grass-based system then the incorporation of a composting barn is likely to increase production levels by less than 100 kg MS/cow, but this may be offset by building the barn for a significantly cheaper capital cost by not having to include feed troughs in the barn or build feed storage bunkers. The benefits of the barn in this situation then is more focused around improving the farm's environmental performance and fine-tuning aspects of the system such as pasture management and reproductive performance to improve productivity and lactation length. In contrast, if the goal is to intensify the system and increase supplementary feeding then the composting barns will also be able to achieve this albeit at a greater capital cost once feed troughs and ancillary equipment is accounted for. The benefits of the barn in this situation is then more related to improved utilisation of feed and facilitation of higher producing cows.

7.4 Critical Components that Affected the Economic Performance of the Composting Barn System

The real internal rate of return before interest and tax (11.62%) for the composting barn gave a considerable increase over the LUDF without a composting barn (8.45%). The real marginal return on capital invested was also high at 27.6%. However, the economic results for the composting barn system should be used with caution due to the large number of assumptions that had to be made to create an investment analysis for a housing system that is very new in New Zealand dairying. As such, this section will discuss the key components that affected the economic outcome of the composting barn on the LUDF rather than discussing and drawing conclusions on the profitability of such a system.

7.4.1 Composting Barn Cost

The cost of designing and constructing the composting barn will vary greatly between farms as a result of 1) difference in farmer preferences and 2) cost of sourcing labour and materials for different regions. The cost of $1,530,000 used in this project was specific to building a composting barn of a set design (Appendix B) for 558 cows in the Canterbury region and included all the ancillary equipment required. A scenario analysis was created to determine the impact an increase in this figure would have on the IRR, NPV and dairy operating profit (Table 7.1). A discount rate of 6% was used to calculate the NPV as this was similar to the post finance and tax return for the current LUDF without a composting barn (6.14%).

Increasing the composting barn construction costs by 20% and 50% resulted in the IRR before interest and tax remaining at 11.6%. This could be expected as changes in the capital cost of the composting barn only affected tax and interest repayments which do not impact on EBIT. The IRR post finance and tax did however show a slight decrease to 8.2% and 8.0%, respectively, once interest and tax were accounted for. Net present value remained positive at both a 20% and 50% increase in capital costs but decreased from the current composting barn system by 8.7% and 5.3%, respectively.

The marginal return decreased considerably with a 20% and 50% increase in composting barn costs, as would be expected, but still showed a good financial return at 20.3% and 14.7%, respectively. Thus, the increase in milksolids revenue appears to absorb the increase in interest costs associated with an increase in the capital costs of construction. It is therefore expected that changes in the milk payout and milk production may have significant impacts on the economic success of the barn and is discussed further in Section 7.4.3 and 7.4.4.

Table 7.1 Scenario analysis of the impact of a change in composting barn construction costs on the financial performance of the composting barn system.

		LUDF with CB	20% increase in CB costs	50% increase in CB costs
Change	CB Cost	$1,530,000	$1,836,000	$2,295,000
Results	IRR (EBIT)	11.6%	11.6%	11.6%
	IRR (Post finance & tax)	8.2%	8.0%	7.9%
	NPV at 6% discount rate (post finance & tax)	$2,967,631	$2,779,429	$2,630,970
	Marginal Return (Post finance & tax)	27.6%	20.3%	14.7%
	EBIT	$1,141,760	$1,131,580	$1,116,338

***CB, composting barn; EBIT, earnings before interest and tax; IRR, internal rate of return; NPV, net present value**

7.4.2 Feed System

The cost of feeding cows on farm over winter and providing supplementary feed in the composting barn during lactation was estimated at $205,560 and was somewhat offset by a saving of $148,340 for winter grazing. However, this feed system and costs associated will vary significantly between farms depending on the ability to utilise the milking platform to grow winter crops, the type and area of crops grown and prices payable for purchased feed. A scenario analysis was therefore conducted to investigate the impact of supplementary feed costs on the economic success of the barn (Table 7.2).

Despite an increase in supplementary feed costs by 30% and 50%, the composting barn system still showed the ability to provide a modest IRR before interest and tax of 11.1% and 10.7%, respectively. The marginal return decreased to 24.3% and 22.0% with a respective 30% and 50% increase in feed costs due to a reduction in the EBIT.

Table 7.2 Scenario analysis of a change in supplementary feed costs on the financial performance of the composting barn (CB) system.

		LUDF with CB	**30% increase feed costs**	**50% increase feed costs**
Change	Feed Costs	$862,409	$924,077	$965,189
Results	IRR (EBIT)	11.6%	11.1%	10.7%
	IRR (Post finance & tax)	8.2%	7.9%	7.6%
	NPV at 6% discount rate (post finance & tax)	$2,967,631	$2,493,575	$2,177,635
	Marginal Return (Post finance & tax)	27.6%	24.3%	22.0%
	EBIT	$1,141,760	$1,080,073	$1,038,961

7.4.3 Milk Production

Several assumptions were made in the current composting barn system regarding the increased milk production of 100 kg MS/cow over the existing LUDF without a composting barn. In reality, the increase in milk production may be higher or lower than this 100 kg MS/cow figure used. As such, scenario analyses were conducted to investigate the impact of milk production on the economic performance of the composting barn system (Table 7.3).

At a decrease of 50 kg MS/cow (535 kg MS/cow) and 25 kg MS/cow (560 kg MS/cow) from the assumed 585 kg MS/cow in the composting barn system, the post finance and tax IRR remained positive but reduced to 6.8% and 7.3%, respectively. The marginal return decreased considerably with a 50 kg MS/cow and 25 kgMS/cow decrease in the assumed 100 kg MS/cow increase to 12.7% and 18.4%, respectively. EBIT decreased by 15.5% and 11.8% with a 50 kg MS/cow and 25 kg MS/cow drop in the assumed milk production, respectively, but still showed profitable returns. In contrast and as expected, increasing per cow production by 25 kg MS/cow and 50 kg MS/cow above the assumed 558 kgMS/cow resulted in higher marginal returns of 28.7% and 33.5%, respectively. Dairy operating profit increased by a smaller 1.5% and 8.1% as a result of increasing per cow production to 125 kg MS/cow and 150 kg MS/cow.

Table 7.3 Scenario analyses of the impact of milk production on the financial performance of the composting barn (CB) system.

		LUDF with CB	-50 kgMS/cow	-25 kgMS/cow	+25 kgMS/cow	+50 kgMS/cow
Change	Production level (kg MS/cow)	585	535	560	610	635
Results	IRR (EBIT)	11.6%	9.5%	10.2%	11.8%	12.6%
	IRR (Post finance & tax)	8.2%	6.8%	7.3%	8.3%	8.8%
	NPV at 6% discount rate (post finance & tax)	$2,967,631	$1,037,850	$1,731,773	$3,119,619	$3,813,542
	Marginal Return (Post finance & tax)	27.6%	12.7%	18.4%	28.7%	33.5%
	EBIT	$1,141,760	$882,916	$977,078	$1,165,403	$1,259,566

7.4.4 Milk Payout

It is clear that the additional increase in milk income as a result of the incorporation of composting barns onto the LUDF is able to absorb potential increases in single cost components of the system at a milk payout of $6.75. This price was used to allow for a fair comparison with the existing LUDF system without a composting barn. However, due to strong volatility in the milk price, scenario analyses were conducted to investigate the impact of a decrease in milk price on the economic performance of the barn (Table 7.4). Scenario analyses of increases in milk price were not performed as it was obvious that at a higher payout, the IRR before interest and tax would increase as no extra costs are involved.

Scenario analysis showed the IRR was highly sensitive to the milk price with the IRR before interest and tax decreasing by an average of 2.4% for every one dollar decrease in the milk payout. Positive returns were shown at all milk payouts analysed, however at $4.00/kg MS the IRR started to become low with an IRR before interest and tax of 4.3% and may not be sufficient the meet the desired returns of farmers. At approximately $5.40/kg MS the marginal return became $0 indicating that no return on the invested capital would be made. The figure of $3.25/kg MS was included in the scenario analysis as this is the breakeven milk price in terms of EBIT for the LUDF operating a composting system.

Table 7.4 Scenario analysis of the impact of a decrease in milk price on the financial performance of the composting barn (CB) system.

		LUDF with CB					
Change	Milk payout ($/kgMS)	6.75	6.00	5.40	5.00	4.00	3.25
Results	IRR (EBIT)	11.6%	9.6%	8.0%	7.0%	4.3%	2.3%
	IRR (Post finance & tax)	8.2%	6.9%	5.8%	5.1%	3.3%	2.0%
	Marginal return (post finance & tax)	27.6%	13.7%	-0.7%	-17.7%	-	-
	NPV 6% discount rate (post finance & tax)	$2,967,631	$1,163,289	-$280,071	-$1,242,311	-$3,647,910	-$5,464,764
	EBIT	$1,141,760	$896,919	$701,061	$570,489	$244,059	$0

7.4.5 Multiple Scenarios

The scenarios in Sections 7.4.1 – 7.4.4 were all conducted on the basis of one component of the system changing. However, in reality often one component has a play on effect on other components of the system. For this reason, this section will conduct scenario analyses based on several changes to the composting barn system.

The first analysis was based on an 'all gone wrong' scenario whereby milk payout declined which had flow on effects on milk production and expenses (Table 7.5). Scenario 1 investigated the impact of a reduction in milk payout to $6.50/kg MS which had flow on effects to a 5% reduction in expenses and a 10% reduction in production. Scenario 2 and 3 investigated the impact of a reduction in milk payout to $6.00/kg MS and $5.50/kg MS, respectively, and a 10% reduction in expenses and 20% reduction in milk production. Scenario 1 was the only situation that gave a positive marginal return of 10.6%. Despite, scenario 2 and 3 not giving a positive marginal return over the existing LUDF, they still gave a modest return with a post finance and tax IRR of 4.8% and 5.5%, respectively. All scenarios returned a positive EBIT.

Table 7.5 Scenario analyses of the impact of 'all gone wrong' situations on the financial performance of the LUDF with a composting barn (CB).

		LUDF with CB	Scenario 1	Scenario 2	Scenario 3
Change	Payout ($/kg MS)	6.75	6.50	6.00	5.50
	Production level (kg MS/cow)	585	527	468	468
	Expenses (% of current)	100%	95%	90%	90%
Results	IRR (EBIT)	11.7%	6.7%	4.8%	5.5%
	IRR (Post finance & tax)	8.3%	9.3%	6.5%	4.1%
	NPV at 6% discount rate (post finance & tax)	$2,967,631	$922,545	-$1,576,079	-$2,538,318
	Marginal Return (Post finance & tax)	27.5%	10.6%	-	-
	EBIT	$1,141,760	$894,095	$578,938	$448,366

The second scenario analysis was based on 'all gone right' scenarios whereby milk payout and production increased (Table 7.6). Scenario 1 investigated the impact of an increase in milk payout to $7.00/kg MS and a 5% increase in production. Scenario 2 and 3 investigated the impact of an increase in milk payout to $7.50/kg MS and $8.00/kg MS, respectively, and 10% increase in milk production. As expected, all scenarios gave a positive return above the existing composting barn system. The marginal return also increased significantly from 27.5% in the existing composting barn system to 36.9%, 50.1% and 58.1% for scenario 1, 2, and 3, respectively. Dairy operating profit also increased in a similar trend.

Table 7.6 Scenario analyses of the impact of 'all gone right' situations on the financial performance of the LUDF with a composting barn (CB).

		LUDF with CB	Scenario 1	Scenario 2	Scenario 3
Change	Payout ($/kg MS)	6.75	7.00	7.50	8.00
	Production level (kg MS/cow)	585	614	644	644
Results	IRR (EBIT)	11.7%	13.4%	15.9%	17.4%
	IRR (Post finance & tax)	8.3%	9.4%	11.0%	12.0%
	NPV at 6% discount rate (post finance & tax)	$2,967,631	$4,503,689	$6,668,728	$7,991,808
	Marginal Return (Post finance & tax)	27.5%	37.4%	51.2%	59.2%
	EBIT	$1,141,760	$1,337,599	$1,631,386	$1,810,922

7.4.6 Summary

The internal rate of return before interest and tax for the LUDF was greater with the incorporation of the composting barns on farm (11.62% with vs. 8.45% without). Scenario analyses showed that milk payout had the single biggest effect on the economic performance of the composting barn system. For every dollar decrease in the milk payout the IRR before interest and tax reduced by an average of 2.4%. The marginal return was also significantly affected by the milk price and at approximately $5.40/kg MS the composting barn system was not able to make a return on capital invested.

Large increases of 20% and 50% in the capital costs of construction did not have a large impact on the IRR as the benefits of the composting barn system, specifically increased milk income, were able to absorb increases in the interest repayments. Similarly, increases of 30% and 50% in supplementary feed costs did not have a large impact on the IRR with the post finance and tax IRR decreasing by 0.6% with a 50% increase in supplementary feed costs.

7.5 Critical Components that Affected the Environmental Performance of the Composting Barn System

7.5.1 Nitrogen Leaching

Nitrogen leaching decreased considerably (32%) from 47 kg N/ha/yr without a composting barn to 32 kg N/ha/yr with the incorporation of the composting barn on the LUDF. The profile of N leaching also changed considerably between the two systems. Without a composting barn, 89.4% (42 kg N/ha/yr) of N leaching came from urine patches, while the remaining 10.6% (5 kg N/ha/yr) came from 'other'. In contrast, with the incorporation of the composting barn on the LUDF the profile of N leaching composed of 9.3% (3 kg N/ha/yr) urinary N leaching and 90.6% (28 kg N/ha/yr) 'other' N leaching (Fig. 7.1). In Overseer®, 'other' leaching is described as the leaching of N beyond the 60 cm root zone from inter-urine areas and incorporates the effects of dung, fertiliser, effluent and soil organic matter mineralisation (AgResearch, 2015).

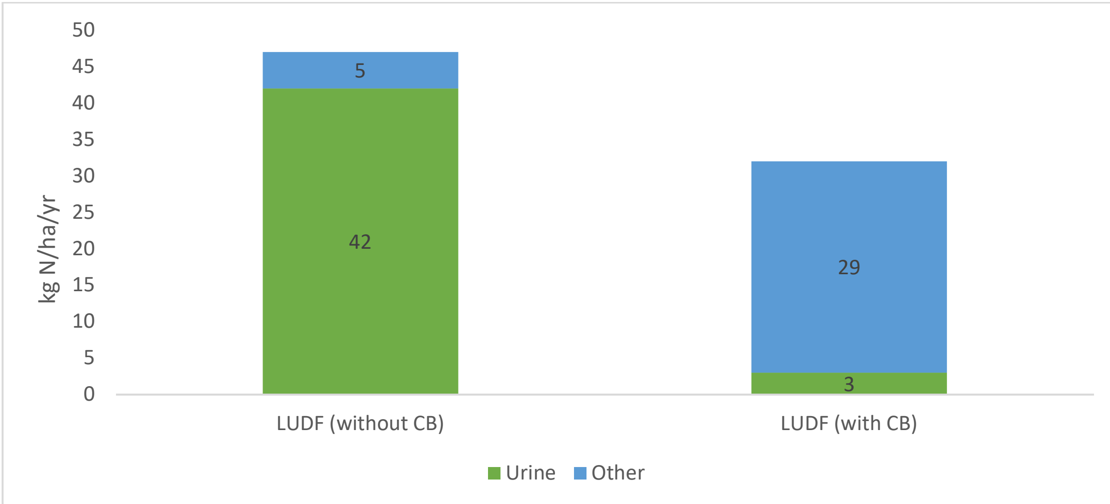

Figure 7.1 Sources of nitrogen (N) leaching (kg N/ha/yr) on the LUDF with and without a composting barn (CB).

Several factors are likely at play to have caused 1) the reduction in urinary N leaching and 2) an increase in 'other' leaching in the composting barn system. The reduction in urinary N leaching from 42 kg N/ha/yr without the composting barn to 3 kg N/ha/yr with the composting barn is largely a result of the ability to operate a duration-controlled grazing system with the cows able to be housed for significant periods of time. Urinary N leaching of 3 kg N/ha/yr under the composting barn system was similar to previous reports of 6.7 kg N/ha/yr (Christensen *et al.*, 2018b) also under a duration-controlled system. By restricting time at pasture to set intervals, grazing time and subsequently urine deposition can be managed so that the volume of urine deposited, and nutrients lost from pasture can be reduced. Grazing time therefore appears to be one of the critical components that affects the nutrient leaching profile in a composting barn system. To determine the impact of grazing time on N leaching, alternate scenarios were run in Overseer® with varying grazing times (Table 7.7).

de Klein and Ledgard (2001) stated that from late summer onwards 30 – 50% of urine deposited remains present in the soil in late autumn. Since, plant uptake in autumn and winter is limited by low temperatures, and excess rain is common during these seasons, any nitrate-N remaining in the soil in late autumn in highly susceptible to leaching. In order to test this theory, grazing times were increased in scenario one by five hours per day from the base grazing times in the composting barn system from February through to April. As expected, total N leaching increased by 6.3% to 34 kg N/ha/yr. Conversely, scenario two investigated the impact of reducing grazing time during late summer and autumn and found only a small reduction of 1 kg N/ha/yr was achieved. A further reduction down to four hours per day grazing from February through to August (scenario 3) resulted in no further reductions to N leaching. When grazing was restricted to eight hours year-round (scenario 4), no urinary N losses occurred causing N leaching to drop to 30 kg N/ha/yr. Any further restrictions in grazing time did not impact on N leaching as Overseer® deemed there to be no urinary N losses, while for every one hour of extra grazing per day N leaching also increased by 1 kg/ha/yr.

Table 7.7 Impact of a change in grazing time on nitrogen (N) leaching (kg N/ha/yr) on the LUDF with a composting barn (CB).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**kg N/ha/yr**	**% change**
LUDF with CB	12	12	12	6	4	4	4	4	6	12	12	12	**32**	**–**
Scenario 1	12	17	17	11	9	9	9	9	9	12	12	12	**34**	**+ 6.3**
Scenario 2	12	6	6	6	4	4	4	4	6	12	12	12	**31**	**- 3.2**
Scenario 3	12	4	4	4	4	4	4	4	6	12	12	12	**31**	**- 3.2**
Scenario 4	8	8	8	8	8	8	8	8	8	8	8	8	**30**	**- 6.3**

The implications of reduced grazing time and subsequently reduced urine and dung depositions on pasture is a reduction in available nutrients for plant growth (Christensen *et al.*, 2018a). Whilst composted bedding and effluent from the composting barn was reapplied to pasture to help retain a balance of nutrients in the system, Overseer® results still showed a lack of nutrient with potassium in particular showing a major decline of -256 kg/ha/yr in the inorganic (plant-available) soil pool. In order to remedy this situation, either replacement nutrients may have to be added through fertiliser to maintain pasture growth or alternatively, reduced pasture growth could be supplemented with brought in feed (Christensen *et al.*, 2018). Neither option was pursued in this research project as it was deemed that this would be an individual decision that would differ between farms. In addition, if maintenance K was to be applied to replace nutrients soil testing would be required to determine the rate of nutrient needed to be applied. This is because the change in potassium from the inorganic soil pool (-256 kg N/ha/yr) is for the whole block (camp and non-camp areas) and hence should not be used to estimate maintenance or change in soil tests (Overseer, 2016).

The second implication of reduced grazing time and reapplication of composted excreta to paddocks is a possible reduction in pasture clover content (de Klein, 2001). Clover relies on areas in the pasture with low N status (i.e. the areas between urine and dung patches) to maintain itself (Brock & Hay, 1996). If compost is then reapplied to pasture at an even concentration, as was the case in the composting barn system, then the clover content of pasture may be reduced causing reductions in pasture quality (de Klein, 2001). Despite these suggestions, Overseer® modelling showed a 12.9% increase in biological N fixation from 171 kg N/ha/yr without the composting barn to 193 kg N/ha/yr with the composting barn, suggesting that clover growth was improved rather than negatively affected from the reduction in grazing time. It is therefore possible that the significant reduction in urinary N depositions combined with the low level of returned N in compost (6.8 kg N/ha/yr) promoted improved clover growth and performance over the existing LUDF system without a composting barn.

The other factor likely to be at play that has caused the increase in 'other' leaching from 5 kg N/ha/yr to 29 kg N/ha/yr in the composting barn system is related to the incorporation of fodder beet and maize silage onto the milking platform. Total N leaching from maize silage and fodder beet contributed 96 kg N/ha/yr and 150 kg N/ha/yr to the total farm N leaching while only representing 13.7% and 6.8% of the total farm area, respectively. Similar findings of disproportionally large volumes of N leaching of 81 kg N/ha/yr to 173 kg N/ha/yr from winter forage crops have also been reported when crops are grazed *in situ* (Smith *et al*., 2012; Shepherd *et al*., 2012). The reason for this can be attributed to the lack of plants available to soak up excreted N combined with the high drainage during the winter season which results in high N leaching (Monaghan *et al*., 2008). However, according to Overseer® no N is leached from urine patches on fodder beet blocks despite cows grazing the crop for four hours per day, which seems unlikely. Instead, all of the N leached appears to come from 'other.' Complete removal of N fertiliser from the fodder beet block showed that it accounted for 34% of the N leaching and reduced N lost to water to 120 kg N/ha/yr. The remaining N leaching must therefore be coming from another source.

Research by Di and Cameron (2002) shows that cultivation for crops increases soil aeration, resulting in the mineralisation of organic N to ammonium (NH_4^+). This NH_3^+ is then rapidly converted to nitrate (NO_3^-) which is easily leached from the soil. It is therefore possible that cultivation and the resulting mineralisation is responsible for the large increase in 'other' leaching. A decrease in the soil organic pool of 495 kg N/ha/yr in Overseer®, of which 258 kilograms of N could be attributed to mineralisation, confirms these findings. As the fodder beet yield was 20 t DM/ha, it can be estimated that for every tonne of fodder beet grown, 7.5 kg N/ha is leached.

The high leaching losses from maize silage (96 kg N/ha/yr) were similar to those found by Ledgard *et al*. (2006) and could also be contributed to soil disturbance and N fertilisers with a decrease of -376 kg N/ha/yr in the soil organic pool. As the maize silage yield was 20 t DM/ha, it can be estimated that for every tonne of maize silage produced, 4.8 kg N/ha is leached.

7.5.2 Greenhouse Gas Emissions

Greenhouse gas emissions increased under the composting barn system with methane and nitrous oxide emissions rising by 14.3% and 534%, respectively. According to Overseer®, the major increase in N_2O emissions was a result of stored effluent from the barn. However, this is not entirely accurate as in the composting barn effluent is composted with the bedding rather than being captured in a bunker below as Overseer® believes it to be. This means that rather than decomposition of effluent under anaerobic conditions, the effluent is decomposed under aerobic conditions with the aid of daily tilling which reduces the production of N_2O as well as CH_4. Overseer® cannot account for this in its modelling, and as such the 534% increase in N_2O emissions is deemed not representative of the system. Currently, very little literature exists on the volume of GHG emissions from composting barns and further research is warranted.

Key components that did however affect the total N_2O emissions in the composting barn, besides effluent storage, was the incorporation of low N feeds in to the system and grazing time. A scenario analysis whereby supplementary feeds were removed from the Overseer® model for the composting barn system and replaced with pasture showed the impact of each feed type on N_2O emissions (Table 7.8). Out of all three supplementary feeds (maize silage, baleage and fodder beet) maize silage had the largest effect on N_2O emissions, reducing emissions by 15.7% and was expected due to having the lowest crude protein (CP) content of 8% (DairyNZ, 2017b). In comparison, the inclusion of baleage and fodder beet had a much lesser effect on N_2O emissions due to their higher CP contents (12 – 17%; 9 – 14%; Dairy NZ, 2017b) with a 6.1% and 4.5% reduction in total N_2O emissions, respectively. Overall, the combined effects of all three supplementary feeds gave a considerable decrease in N_2O emissions of 26.0%. These results confirm findings by van Vuuren *et al*. (1993) that the incorporation of low N feeds will result in lower N intake, urinary N excretion and less N_2O loss from excreta.

Table 7.8 Impact of the removal of low nitrogen feeds on nitrous oxide (N_2O) emissions in the composting barn system. Crude protein (CP) per cent was based on published data by DairyNZ (2017b).

	CP%	Total N_2O emissions	% Difference
LUDF with composting barn	-	20,920	-
Removal of maize silage	8%	24,197	+15.7%
Removal of baleage	12 – 17%	22,210	+6.1%
Removal of fodder beet	9 – 14%	21,870	+4.5%
Removal of maize silage, baleage and fodder beet	-	26,355	+26.0%

Grazing time also had a large effect of nitrous oxide emissions as it changed the proportion of urine and dung excreted between the composting barn and paddock. Scenario analysis using the same grazing times in Table 7.7 were used to also determine the impact on N_2O emissions (Table 7.9). Scenario one and four which had the greatest overall grazing time showed significantly reduced N_2O

emissions compared to the proposed LUDF composting barn system with reductions of 10.5% and 38.5%, respectively. In contrast, scenario two and three which reduced grazing time had increased N_2O emissions of 4.1% and 6.2%, respectively. These results were expected due to the inability of Overseer® to model effluent in composting barns. As such, these results may not be representative of nitrous oxide emissions from composting barn systems and further research is warranted.

Table 7.9 Impact of grazing time (hours/day) on paddock (P), composting barn (CB) and total nitrous oxide (N_2O) emissions (kg CO_2-e/ha/year) from the LUDF with a composting barn.

	Grazing time												**N_2O emissions**			
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	P	CB	Total	**% change**
LUDF with CB	12	12	12	6	4	4	4	4	6	12	12	12	219	19,829	20,920	**–**
Scenario 1	12	17	17	11	9	9	9	9	9	12	12	12	334	17,526	18,730	**- 10.5**
Scenario 2	12	6	6	6	4	4	4	4	6	12	12	12	147	20,760	21,774	**+ 4.1**
Scenario 3	12	4	4	4	4	4	4	4	6	12	12	12	147	21,199	22,219	**+ 6.2**
Scenario 4	8	8	8	8	8	8	8	8	8	8	8	8	13	12,019	12,875	**- 38.5**

Unlike N_2O, the increase in methane emissions from 9,997 kg CO_2 equivalents (CO_2-e)/ha/year to 11,424 kg CO_2-e/ha/year under the composting barn system came as a result of increased enteric fermentation. This is expected as feed intake is the major driver of enteric CH_4 emissions (Beukes *et al*., 2010) and total feed consumed increased from 5.3 t DM/cow without the composting barn to 5.6 t DM/cow with the composting barn. However, feed efficiency also improved from 10.95 kg DM/kg MS without the composting barn to 9.51 kg DM/kg MS with the composting barn. Thus, emission's intensity (CH_4/unit animal product) improved with the addition of a composting barn system on the LUDF through improved feed conversion efficiency which resulted in a decrease in CH_4 emissions from 5.92 kg CO_2-e/kg MS without the barn to 5.60 kg CO_2-e/kg MS with the barn (Table 7.10). These findings align with previous reports that feed intake is the main driver of GHG emissions and therefore more efficient animals can produce the same or greater milksolids with less feed and lower CH_4 output (Beukes *et al*., 2010).

Table 7.10 Feed conversion efficiency and emission's intensity for the LUDF with and without a composting barn.

	LUDF (without CB)	**LUDF (with CB)**
kg DM consumed/ha	18,500	19,400
kg MS/ha	1,690	2,039
FCE (kg DM/kg MS)	10.95	9.51
CH_4 (kg CO_2-e/ha/yr)	9,997	11,424
Emission's intensity (kg CH_4/kg MS)	5.92	5.60

7.5.3 Summary

Nitrogen leaching and greenhouse gas emissions were significantly affected by the inclusion of composting barns on the LUDF. Total nitrogen leaching decreased in the composting barn system by 32%, while the profile of N leaching changed from one dominated by urinary N excretion (without composting barn) to one dominated by 'other' leaching (with composting barn). The two critical components that affected N leaching were grazing time and growing of maize silage and fodder beet on the milking platform. The inability of Overseer® to model composting barns severely impacted on the nitrous oxide emissions from the farm system and were deemed to be not representative of the system. Further research is required to understand how the composting process and daily tilling of the bedding affects nitrous oxide emissions. Despite this, through scenario analysis, it was possible to detect that the use of low N feeds, particularly maize silage, was a critical component that affected excreta N_2O emissions. Methane emissions on a per product basis reduced as an indirect effect of the composting barn system through improved feed conversion efficiencies. As such, the level of feed offered per cow was the critical component affecting methane emissions.

7.6 Key Constraints to the Adoption of Composting Barns in New Zealand

7.6.1 Lack of Knowledge and Previous Adopters

One of the key constraints to the adoption of composting barns in New Zealand is the lack of knowledge on the barn design and construction as well as lack of previous adopters. Findings from the literature review showed a severe gap in knowledge on the environmental performance and incorporation and management of composting barn systems on New Zealand dairy farms. As such, a number of assumptions had to be made in this research project surrounding the Overseer® models and investment analysis. Further research is therefore required to refine and validate these assumptions.

Furthermore, this research project has focused on the impact of composting barns on the whole farm system but has touched little on the barn design, composting process and outcomes of using a range of bedding materials in different climatic locations. These are vital components of the composting barn that are critical to the success of the system and are not yet fully understood. As reported by Woodford *et al*. (2018), failures by early adopters to understand the key principles of composting barns can lead to other farmers becoming non-adopters by mistaking management failure for technology failure. Research and development programmes are therefore necessary to investigate and understand the barn design and composting process within the New Zealand environment to help facilitate farmer learnings of these systems. Without such programmes, adoption of composting barns in New Zealand is likely to be slow.

7.6.2 Change in Management System

New Zealand farmers, particularly the older generation, tend to have a mindset for year-round, 24/7 pastoral grazing. Over the past 10 years however, there has been a trend for intensification through increasing supplementary feeding and incorporating off-paddock infrastructure such as feedpads and stand-off pads on farms (DairyNZ, 2008, 2017a; Mounsey, 2015). These additions require a change in management system from a 24/7 grazing system to a duration-controlled grazing system whereby cows are brought off pasture for supplementary feeding or to reduce pasture damage and environmental impacts. While there is the perception that housing structures require a significant management change, in reality the change in practices from hard-floor shelters to composting barns are small. The biggest change is a new focus on compost management, with twice-daily tilling and moisture and temperature measurements being key requirements of the barn. This presents a constraint to adoption, however with research and extension programmes it is possible that farmer learning over time will overcome this constraint.

7.6.3 Adding Value to the Farm

Housing facilities in New Zealand are often met with scepticism. As such, the impact on land value from incorporating a housing facility such as a composting barn on farm is uncertain and may be a constraint to adoption by some farmers. Despite this, a similar study by Journeaux and Newman (2015) reported that the construction of a barn would increase the capital value of the farm but may not be directly proportional to the cost of that barn. Rather, it is more likely that any increase in value of the farm would be proportional to the increase in production resulting from the barn and also proportional to the marginal value of that extra production.

7.6.4 Access to Finance

Many dairy farmers are capital constrained and the finances required to invest in composting barns would likely have to be borrowed. As debt levels in the dairy industry are currently high, many farmers are likely to be reluctant to increase debt levels further which poses a key constraint to the adoption of composting barns. Innovative financing options would be required to overcome this constraint.

7.6.5 Availability of Bedding

If composting barns were to be rapidly adopted then the availability of sawdust, the typical cow bedding material used, may not be sufficient to meet the demands of 3 – 5 m^3/cow/year, or may become too expensive (K. Woodford, personal communication, September 25, 2018). Other alternatives would therefore be needed to overcome this constraint. Miscanthus, a long-lived perennial grass, is currently showing potential as a bedding material with limited research studies identifying immediate acceptance of Miscanthus as bedding by cows (Van Weyenberg *et al.*, 2015). The grass could also be grown on farm and harvested once per year (in late winter or early spring) when it's in a woody state, providing the farmer with greater control over their system and certainty of bedding costs.

Chapter 8

Conclusions

The objective of this research project was to determine the economic and environmental implications of incorporating composting barns onto New Zealand dairy farms, and more importantly to identify the critical components that affect both the economic and environmental performance of the barn. The hope was that this project would act as a starting point for further research into composting barn systems in New Zealand.

Preliminary work from this study, based on a number of assumptions, indicated that the incorporation of composting barns on farm could improve both the economic and environmental performance of dairy farms through improved production and the ability to operate a duration-controlled grazing system. Overseer® modelling indicated a 32% decrease in nitrogen leaching on the Lincoln University Dairy Farm from 47 kg N/ha/yr without a composting barn to 32 kg N/ha/yr with a composting barn. These figures are estimates only and should be used with caution due to the margin of error within Overseer® and the inability of the programme to model composting barns. The source of N leaching also shifted from one dominated by leaching from urine patches (without composting barn) to one dominated by 'other' leaching, specifically from fertiliser and mineralisation of N from cultivation of crops. The key component that affected the reduction in N leaching was the ability to operate a duration-controlled grazing system whereby cows were housed in the barn for varying amounts of time depending on the leaching risk. On the other hand, the key component that increased 'other' leaching was the type and area of crops grown on the milking platform.

Total methane produced on the LUDF increased by 14.3% with the incorporation of the composting barn but decreased on a per kilogram of milk solids basis from 5.92 kg CO_2-e/kg MS to 5.60 kg CO_2-e/kg MS due to improvements in feed conversion efficiency. Nitrous oxide could not be accurately measured due to the inability of Overseer® to model effluent and the composting process within the composting barn. Nevertheless, it was possible to determine that the incorporation of low protein feeds into the diet, particularly maize silage, was a critical component affecting N_2O emissions.

Excel-based modelling indicated an improvement in the internal rate of return of the LUDF with the incorporation of the composting barns on farm with the internal rate of return before interest and tax increasing from 8.45% without the barn to 11.62% with the barn. The marginal return on capital invested was 27.6%. Milk payout was identified as the key component affecting the economic performance of the barn and for every one dollar reduction in the milk payout, the IRR before interest and tax reduced by an average of 2.4%. Significant increases in the capital costs of construction had little impact on the IRR as the increased milk revenue from the composting barn system absorbed increases in debt servicing.

Chapter 9

Limitations and Future Research

This research project was based on theoretical modelling of composting barn systems which required a large number of assumptions to be made due to the pioneering stage of such barns in New Zealand. These assumptions included the feed system, diet, lactation length and milksolids produced which had significant implications for both the environmental and economic performance of the composting barn system. An attempt to reduce the effect of these assumptions by putting emphasis on the critical components which affected both the environmental and economic performance of the composting barn system was used rather than drawing conclusions on the absolute values of the outcome of the system. Furthermore, this study was limited to the Lincoln University Dairy Farm in Canterbury and as such it cannot be guaranteed that the same findings will be replicated on other farms and regions in New Zealand.

Modelling of the environmental performance of the composting barn system was conducted using Overseer® Nutrient Budgets and was constrained to version 6.3.0 of Overseer®. This had large limitations for the study due both to the margin of error contained within Overseer® and the inability of Overseer® to model composting barns. Despite these limitations, Overseer® was still considered the best tool available for use and over time it is expected that the accuracy of Overseer® will improve.

Future research using formalised research trials is required to understand composting barns in the New Zealand context to test and validate the assumptions made in this study. Particular research is also needed to understand the composting process of bedding and effluent within the barn to inform Overseer® modelling and industry understanding. Specifically, greater understanding of nitrous oxide emissions from the composting barn is required.

In addition, this study focuses on a seasonal milking system only. However, the incorporation of composting barns on farm provide great opportunity to change to a winter milking system which would allow farmers to further increase productivity and take advantage of winter premiums. Research is required to understand how a winter milking system would change the economic and environmental performance of composting barns.

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Appendix A

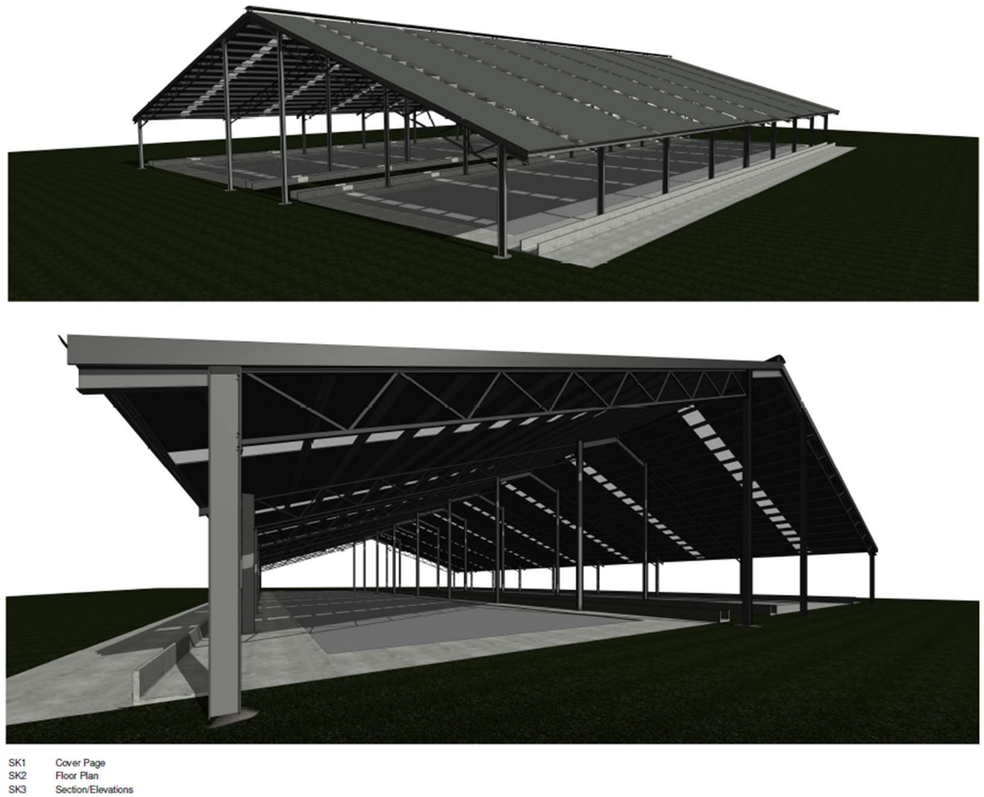
A.1 Allcock Composting Barn and Farm System

The Allcock composting barn in the Waikato was one of the first composting barns built in New Zealand and is now in its fourth year of operation. The incorporation of the composting barn into the farm system required a change in management practice from a typical 24/7 grazing system to one where the cows spend part of every day in the barn and part outside grazing. Grazing times vary throughout the year depending on weather conditions. Over winter, cows spend much of their time in the barn and are allowed outside to graze for a break of grass each day for 2 – 5 hours. All cows calve in the barn after which they spend most of their time outside coming in the barn twice a day for feeding only. Once the days start getting hot, approximately mid-November through to April, the cows spend all day in the barn and go out at night when it is cooler. During April and May they come in the barn to feed twice a day before the process starts again in winter.

Prior to the composting barn, farm production varied from 88,000 – 99,000 kg MS/yr. After incorporation of the composting barn into the farm system milk production lifted to 128,000 kg MS in the first year, 134,000 kg MS in the second year and 147,000 kg MS in the third year. The majority of this production increase has come from improved per cow production from 380 kg MS/cow without the barn to 544 kg MS/cow in the third year of operating a composting barn system. Incorporation of supplementary feed has played a part in the increased production with home-grown maize silage being one of the key feed components alongside pasture. The design of the Allcock composting barn is basically an open-sided roofed barn structure with two composting bays separated by a central feed lane with feed troughs either side of the composting area. Total cost of the 280 cow barn was approximately $900,000 and included concreting the surrounds of the barn and purchasing of a mixer wagon and small tractor for tilling the bedding.

Appendix B

B.1 LUDF Composting Barn Design



Calder Stewart

Preliminary
CN2018-xxxx
SK1

Figure B.1 Three-Dimensional model of composting barn designed by Calder Stewart.

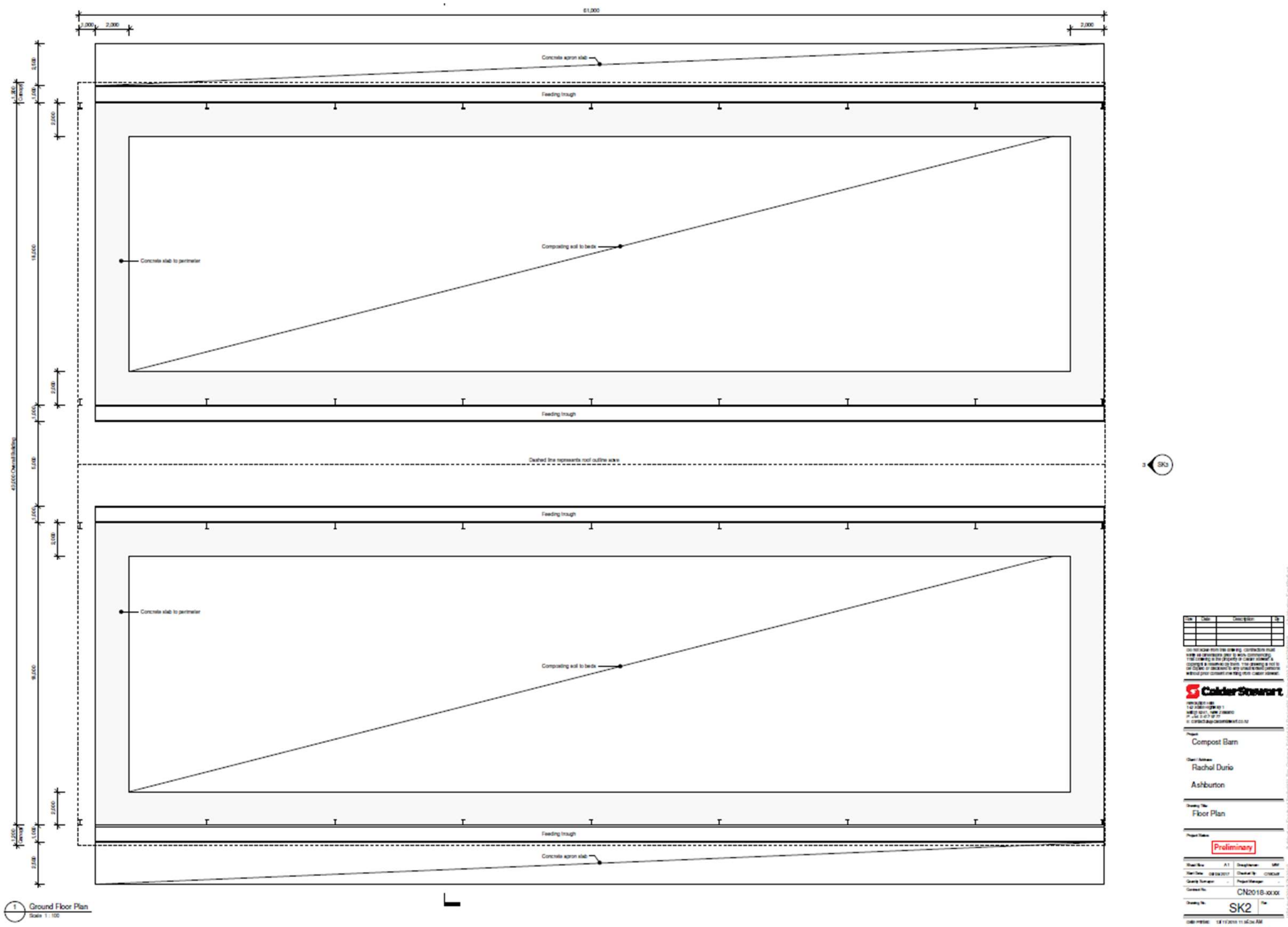


Figure B.2 Composting barn floor plans designed by Calder Stewart.

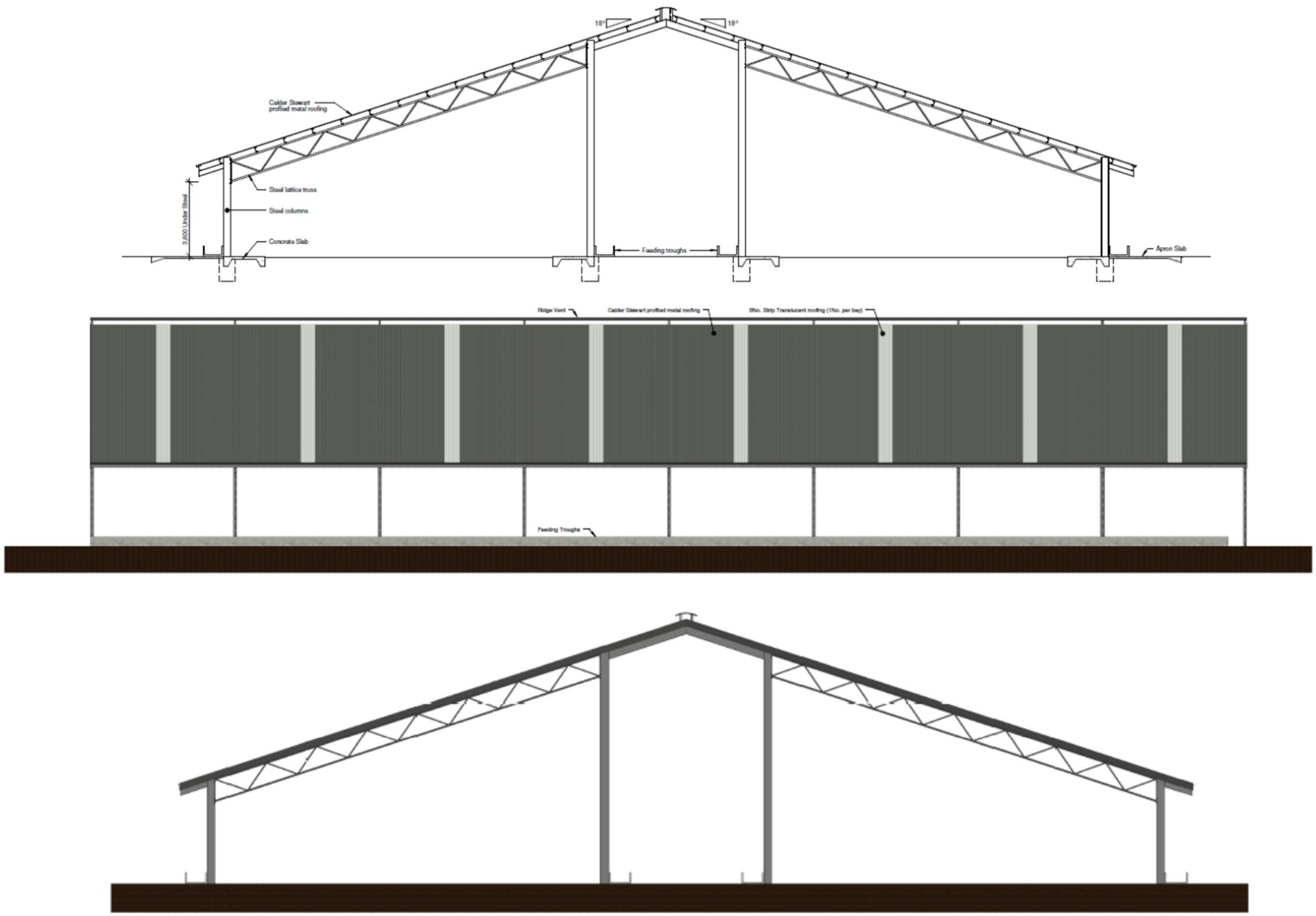


Figure B.3 Composting barn elevation and side-view designed by Calder Stewart.

Appendix C

C.1 LUDF Map

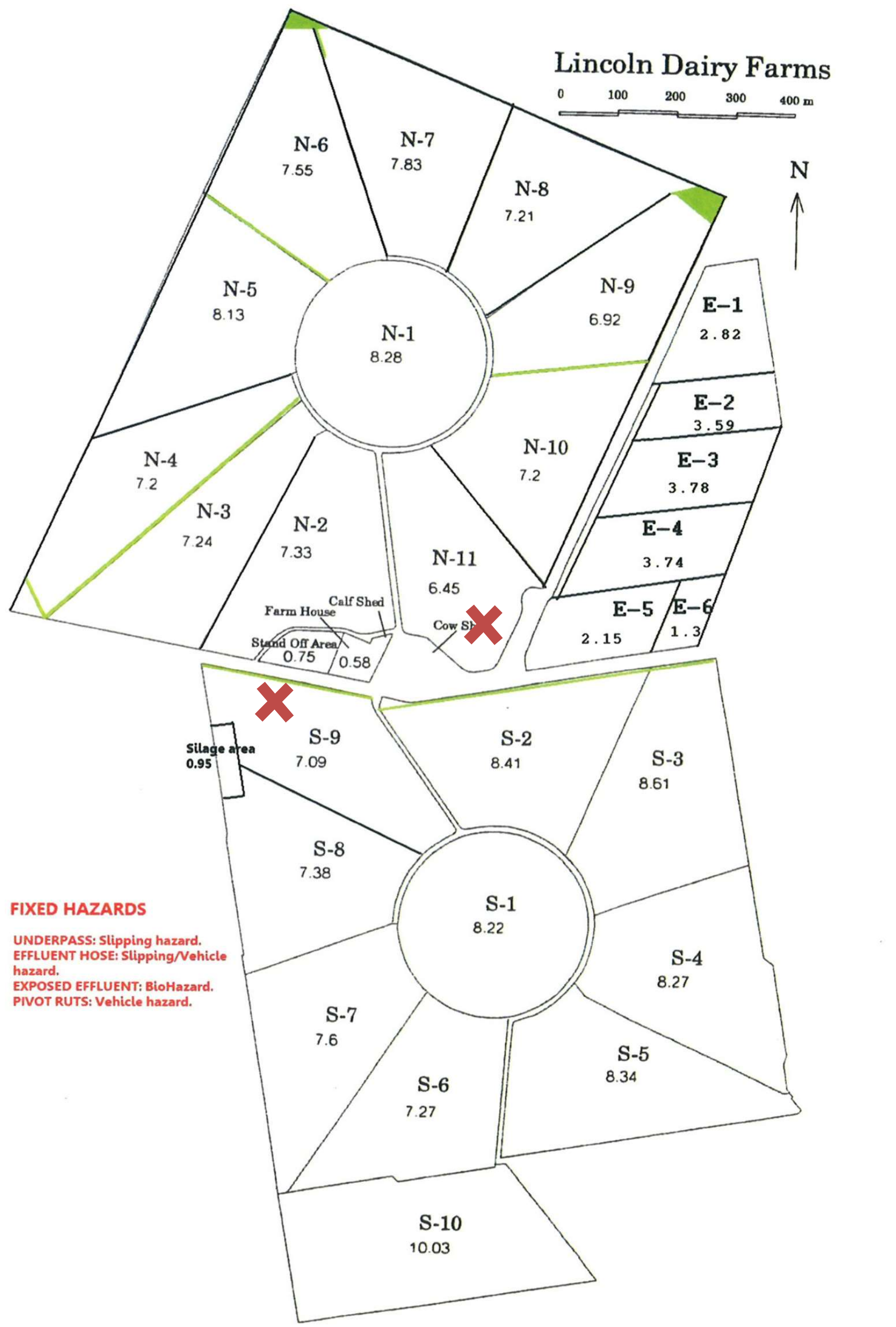


Figure B.4 LUDF farm map. 'X' indicates potential locations for the composting barns.

Appendix D

D.1 Fodder Beet Growing Costs

Table D.1 Establishment details and approximate cost for a fodder beet crop. Retrieved from Matthew *et al*. (2016).

Item	Details	Cost ($/ha)
Preparation	Spray (September): Roundup 4 L/ha (glyphosate 510 g/L)	47
Cultivation	Plough, roll, power harrow	285
Sowing	Precision drilled mid-October	210
Seed	80,000 monogerm beet seeds	356
Pre-Emergence Spray	Roundup 1 L/ha (glyphosate 510 g/L) + Nortron 4 L/ha (ethofumesate 500 g/L) + Lorsban 250 mL/ha (chlorpyrifos 500g/L)	256
Post-Emergence Spray	Goltix 1.5 kg/ha (metamitron 700 g/kg) + Betanel Forte 1.1 L/ha (phenmedipham 160 g/L, desmedipham 160 g/L) + Lorsban 250 mL/ha (chlorpyrifos 500 g/L)	300
Second Post-Emergence Spray	Goltix 1.5 kg/ha (metamitron 700 g/kg) + Betanel Forte 1.2 L/ha (phenmedipham 160 g/L, desmedipham 160 g/L) + Lorsban 250 mL/ha (chlorpyrifos 500 g/L) + Versatil 1 L/ha (clopyralid 300 g/L)	417
Fertiliser	Broadcast: 1600 kg/ha cropfine lime, 100 kg/ha muriate of potash, 100 kg/ha salt, 50 kg/ha calmag. Drilled with seed: 150 kg/ha DAP boron boost	54
	Total Cost	**2,225**

D.2 Maize Silage Growing and Harvesting Costs

Table D.2 Establishment, growing and harvest details and estimated costs for maize silage. Adapted from Pioneer (2018).

Item	Details	Cost ($/ha)
Preparation	Spray: Roundup	70
Fertiliser	1.25 t/ha lime, base fertiliser and application	330
Cultivation		360
Seed	Pioneer® brand P9911 maize seed @ 1.35 bags/ha, FAR maize seed levy ($8.00/80,000 kernels @ 1.35 bags/ha), LumiGEN L-401 seed treatment @ 1.35 bags/ha	720
Fertiliser	Starter fertiliser and application	190
Planting		155
Pre-Emergence Spray	Herbicide plus application	90
Post-Emergence Spray	Herbicide plus application	90
Sidedress Application		80
Sidedress Nitrogen		100
	Total growing cost	**2185**
Harvesting and Stacking		1030
Covering		165
Inoculant	Pioneer brand 11C33 maize specific inoculant	345
	Total harvest cost	**1540**
	Total growing and harvest costs	**3725**

Appendix E

E.1 Annual Budget

Table E.1 Full annual budget for the LUDF with and without a composting barn (CB).

INCOME	LUDF (without CB)	LUDF (with CB)
Milk Income (MS x $6.75)	1,826,753	2,203,403
DairyNZ Levy (MS x $0.036)	-9,743	-11,751
Stock Sales	125,712	117,955
Stock Purchased	-32,685	-32,685
TOTAL INCOME	**1,910,037**	**2,276,921**
EXPENSES		
Wages	248,910	273,910
Animal Health	65,370	65,370
Breeding and Herd Improvement	52,799	52,799
Farm Dairy	9,051	13,057
Electricity (farm dairy and water supply)	27,657	35,907
Bedding	0	44,640
Supplement Made/Purchased/Cropped	93,027	205,560
Calf Feed	30,171	27,950
Young Stock Grazing	123,198	109,252
Winter Cow Grazing	148,340	0
Fertilisers	31,931	35,891
Nitrogen	40,228	43,264
Irrigation (electricity/rates)	45,256	45,256
Regrassing	10,057	12,852
Weeds and Pests	251	251
Vehicle	7,543	11,193
Fuel	10,057	21,500
R&M Land and Buildings	22,628	24,628
R&M Plant and Equipment	20,114	20,114
Freight and general farm expenses	12,571	1,411
Administration	22,628	22,628
Insurance	10,057	12,000
Rates	12,571	13,500
Income tax	263,880	373,280
GST account balance	-167,180	-218,685
Financial charges	0	-112,924
Overdraft interest	-1,239	-11,859
TOTAL EXPENSES	**1,139,877**	**1,122,745**
SURPLUS (DEFICIT)	770,160	1,154,175

E.2 Investment Appraisal for LUDF without a Composting Barn

Table E.2 Investment appraisal for the LUDF without a composting barn.

Total Annual Income	1,910,037	100%												
Total Annual Expenses	-875,997	100%												
		Cash	Tax	Cash	Tax	Cash	Tax	Cash	Cash	Tax	Cash	Tax	Cash	Tax
Income Adjustment		100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Expenses Adjustment		100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Years	0	1		2		3		4	18		19		20	
Land	-7,622,652												16,961,012	
Land Developments	-581,030												286,805	
Building	-389,000												323,796	
Plant	-738,646												437,741	
Vehicles	-179,039												41,315	
Machinery	-218,543												39,422	
Irrigation	-646,094												269,129	
Water Infrastructure	-95,862												44,792	
Effluent System	-130,260												45,419	
Livestock	-1,134,195												1,134,195	
Loan	0												0	
													0	
Depreciation			-218,019		-193,649		-172,975			-43,260		-39,899		-36,839
Interest		0	0	0	0	0	0	0	0	0	0	0	0	0
Principal		0		0		0		0	0		0		0	
Income		1,938,687	1,938,687	1,967,768	1,967,768	1,997,284	1,997,284	2,027,243	2,497,069	2,497,069	2,534,525	2,534,525	2,572,542	2,572,542
Expenses		-893,517	-893,517	-911,387	-911,387	-929,615	-929,615	-948,207	-1,251,139	-1,251,139	-1,276,162	-1,276,162	-1,301,685	-1,301,685
Tax Losses Carried Forward					0		0			0		0		0
Taxable Income			827,152		862,732		894,695			1,202,669		1,218,464		1,234,019
Tax		-263,880	-263,880	-275,622	-275,622	-286,169	-286,169	-295,780	-387,801	-387,801	-393,013	-393,013	-398,146	-398,146
Nominal Cashflow	-11,735,322	781,291		780,759		781,500		783,256	858,129		865,350		20,456,337	
Real Cashflow	-11,735,322	765,971		750,441		736,425		723,608	600,827		594,003		13,766,528	
Nominal Cashflow (EBIT)	-11,735,322	1,045,171		1,056,381		1,067,669		1,079,036	1,245,930		1,258,363		20,854,483	
Real Cashflow (EBIT)	-11,735,322	1,024,677		1,015,360		1,006,089		996,863	872,349		863,779		14,034,469	
Nominal														
Real														

	Post-Finance & Tax				EBIT	
	Nominal	Real			Nominal	Real
IRR	8.27%	6.14%		IRR	10.62%	8.45%
NPV	14,730,377	8,094,757	2.0%			
	8,202,910	3,469,235	4.0%			
	3,350,639	0	6.1%			
	358,560	-2,160,394	8.0%			
	-2,001,579	-3,882,371	10.0%			

E.3 Investment Appraisal for LUDF with a Composting Barn

Table E.3 Investment appraisal for the LUDF with a composting barn.

Total Annual Income	2,276,921	100%												
Total Annual Expenses	862,390	100%												
		Cash	Tax	Cash	Tax	Cash	Tax	Cash	Cash	Tax	Cash	Tax	Cash	Tax
Income Adjustment		100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Expenses Adjustment		100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Years	0	1		2		3		4	18		19		20	
Land	-7,622,652												16,961,012	
Land Developments	-581,030												286,805	
Building	-2,116,298												1,632,675	
Plant	-738,646												437,741	
Vehicles	-189,039												42,389	
Machinery	-218,543												39,422	
Irrigation	-646,094												269,129	
Water Infrastructure	-95,862												58,545	
Effluent System	-130,260												45,419	
Livestock	-1,077,630												1,077,630	
Loan	0												0	
New Loan	1,737,298												-1,737,298	
New Loan Interest		-112,924	-112,924	-112,924	-112,924	-112,924	-112,924	-112,924	-112,924	-112,924	-112,924	-112,924	-112,924	-112,924
Depreciation			-272,771		-245,823		-222,793			-72,074		-67,842		-63,948
Interest		0	0	0	0	0	0	0	0	0	0	0	0	0
Principal		0		0		0		0	0		0		0	
Income		2,311,075	2,311,075	2,345,741	2,345,741	2,380,927	2,380,927	2,416,641	2,976,711	2,976,711	3,021,362	3,021,362	3,066,682	3,066,682
Expenses		-879,638	-879,638	-897,230	-897,230	-915,175	-915,175	-933,478	-1,231,705	-1,231,705	-1,256,339	-1,256,339	-1,281,466	-1,281,466
Tax Losses Carried Forward					0		0			0		0		0
Taxable Income			1,158,666		1,202,687		1,242,959			1,672,932		1,697,181		1,721,269
Tax		-373,280	-373,280	-387,807	-387,807	-401,097	-401,097	-413,416	-542,988	-542,988	-550,990	-550,990	-558,939	-558,939
Nominal Cashflow (post EBI	-11,678,758	945,233		1,060,704		1,064,655		1,069,746	1,202,019		1,214,033		20,226,822	
Real Cashflow (post EBIT)	-11,678,758	926,699		1,019,515		1,003,249		988,280	841,605		833,350		13,612,071	
Nominal Cashflow (pre EBIT	-11,678,758	1,431,437		1,448,510		1,465,752		1,483,162	1,745,006		1,765,023		21,145,838	
Real Cashflow (pre EBIT)	-11,678,758	1,403,370		1,392,263		1,381,211		1,370,213	1,221,782		1,211,566		14,230,543	

		Post Finance & Tax			EBIT	
		Nominal	Real		Nominal	Real
IRR		10.37%	8.21%	IRR	13.85%	11.62%
NPV	2%	19,348,989	11,938,586			
	4%	12,060,080	6,712,860			
	6%	6,886,209	2,967,631			
	8.2%	2,832,040	0			
	10%	423,879	-1,783,559			
	12%	-1,610,100	-3,307,754			

E.4 Marginal Return for the LUDF with a composting barn

Table E.4 Marginal return on capital invested for the LUDF with a composting barn.

Marginal Return						
Nominal	-1,737,298	163,942	667,751	684,252	699,906	689,502
Real	-1,737,298	160,728	641,822	644,786	646,605	464,015

		Post Finance & Tax	
IRR		Nominal	Real
		30.32%	27.61%
NPV	15.0%	1,347,549	1,035,948
	20.0%	772,423	535,288
	27.6%	163,325	0
	30.0%	18,085	-128,592
	35.0%	-235,070	-353,787
	40.0%	-435,185	-532,882